PL-TR-95-2152

# CRRES/SPACERAD Heavy Ion Model of the Environment, CHIME

## For Single Particle Radiation Effects in Space Near Earth

**User's Guide for Version 3.5**

D.L. Chenette
J.D. Tobin
S.P. Geller

Lockheed Martin Advanced Technology Center
Palo Alto Research Laboratory
Space Sciences Laboratory   O/H1-11   B/252
3251 Hanover Street
Palo Alto, CA   94304-1191

10 February 1997
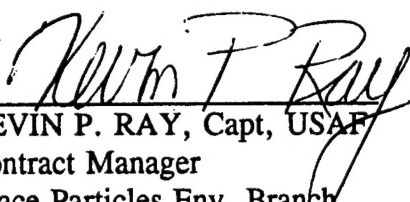
Final Report
11 March 1991 - 6 December 1996

Approved for public release; distribution unlimited.
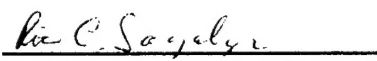
PHILLIPS LABORATORY          DTIC QUALITY INSPECTED 3
Directorate of Geophysics
AIR FORCE MATERIEL COMMAND
HANSCOM AIR FORCE BASE, MA  01731-3010

19970305 054

"This technical report has been reviewed and is approved for publication"


KEVIN P. RAY, Capt, USAF
Contract Manager
Space Particles Env. Branch
Space Physics Division

EDWARD G. MULLEN, Chief
Space Particles Env. Branch
Space Physics Division


RITA SAGALYN, Director
Space Physics Division

# REPORT DOCUMENTATION PAGE

Public reporting burden for this collection of information is estimated to average 1 hour per response, including the time for reviewing instructions, searching existing data sources, gathering and maintaining the data needed, and completing and reviewing the collection of information. Send comments regarding this burden estimate or any other aspect of this collection of information, including suggestions for reducing this burden, to Washington Headquarters Services, Directorate for Information Operations and Reports, 1215 Jefferson Davis Highway, Suite 1204, Arlington, VA 22202-4302, and to the Office of Management and Budget, Paperwork Reduction Project (0704-0188), Washington, DC 20503.

| 1. AGENCY USE ONLY (Leave blank) | 2. REPORT DATE 10 February 1997 | 3. REPORT TYPE AND DATES COVERED Final 11 March 1991–6 December 1996 |
|---|---|---|

**4. TITLE AND SUBTITLE**
CRRES/SPACERAD Heavy Ion Model of the Environment, CHIME, For Single Particle Radiation Effects in Space Near Earth, User's Guide for Version 3.5

**5. FUNDING NUMBERS**
Contract:
F19628-90-C-0101
PE 7601
TA 22 WU LB

**6. AUTHOR(S)**
D. L. Chenette, J. D. Tobin, and S. P. Geller

**7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)**
Lockheed Martin Advanced Technology Center
Space Sciences Lab, O/H1-11 B/252
3251 Hanover St.
Palo Alto, CA 94304-1191

**8. PERFORMING ORGANIZATION REPORT NUMBER**

**9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)**
Phillips Laboratory
29 Randolph Road
Hanscom AFB, MA 01731-0310

Contract Manager: Capt. Kevin Ray/GPSP

**10. SPONSORING/MONITORING AGENCY REPORT NUMBER**
PL-TR-95-2152

**11. SUPPLEMENTARY NOTES**

**12a. DISTRIBUTION/AVAILABILITY STATEMENT**
approved for public release;
distribution unlimited

**12b. DISTRIBUTION CODE**

**13. ABSTRACT (Maximum 200 words)**

A new time-dependent model of the heavy ion space radiation environment has been developed which describes the galactic cosmic ray, anamalous component, and solar energetic particle heavy ions fluxes and their temporal and spatial variations in space near earth. This model, the CRRES/SPACERAD Heavy Ion Model of the Environment (CHIME) is incorporated in a set of computer software modules which allow a user to define a model specific to a period of time or a level of solar activity, and a location or orbit near earth. A brief description of the models forming the basis of CHIME is presented. Documentation, installation, and usage notes specific to the implementation of CHIME on PC-compatible systems are provided in this User's Guide.

**14. SUBJECT TERMS**
radiation effects, single event upset, space environment, cosmic rays, solar flares

**15. NUMBER OF PAGES**
78

**16. PRICE CODE**

| 17. SECURITY CLASSIFICATION OF REPORT | 18. SECURITY CLASSIFICATION OF THIS PAGE | 19. SECURITY CLASSIFICATION OF ABSTRACT | 20. LIMITATION OF ABSTRACT |
|---|---|---|---|
| unclassified | unclassified | unclassified | SAR |

NSN 7540-01-280-5500

## CONTENTS

iii

## FIGURES

## TABLES

# SYMBOLS AND ABBREVIATIONS

| | |
|---|---|
| AC | the Anomalous Component of the cosmic ray flux near earth |
| AU | Astronomical Unit, the mean distance from sun to earth |
| CHIME | CRRES/SPACERAD Heavy Ion Model of the Environment |
| CRRES | Combined Release and Radiation Effects Satellite |
| E | kinetic Energy |
| GeV | giga electron volts (kinetic energy units) |
| GCR | Galactic Cosmic Rays |
| LET | Linear Energy Transfer |
| LIS | Local Interstellar Spectrum of the galactic cosmic rays |
| MeV | mega electron volts (kinetic energy units) |
| MV | megavolts (units for the solar modulation parameter) |
| MS/DOS | MicroSoft Disk Operating System |
| SEP | Solar Energetic Particle |
| SEU | Single Event Upset |
| Z | atomic number (of an element) |
| $\Phi$ | the level of solar modulation parameter |

# 1. INTRODUCTION TO CHIME

## 1.1 Overview

Accurate estimates of the frequency of single event effects require accurate models of the fluxes of heavy ions which cause them. These flux models must account for the multifarious temporal variations of ion flux intensity and their significant energy- and species-dependencies. The flight of the Combined Release and Radiation Effects Satellite (CRRES), which included both state-of-the-art instrumentation to measure the heavy ion environment as well as a comprehensive MicroElectronics Package (MEP) for on-orbit tests of single-event upsets, provided both the impetus and the opportunity to develop an improved model of the near-earth heavy ion environment. The CRRES/SPACERAD Heavy Ion Model of the near-earth space Environment (CHIME) is a result of this opportunity. This document is a brief description of CHIME and a user's guide to running the program on PC-compatible computers.

The CRRES/SPACERAD Heavy Ion Model of the near-earth space Environment (CHIME) is a set of programs and data files which permit a user:
    (1) to calculate accurate models of the fluxes and energy spectra of ions in
        the near-earth space environment under a wide variety of conditions,
    (2) to convert these particle flux models to linear energy transfer (LET) spectra,
and (3) to estimate rates for single-particle radiation effects in microelectronic
        devices exposed to the environment model fluxes.

CHIME is the result of a collaboration between the Lockheed Martin Advanced Technology Center, Louisiana State University, and The University of Chicago, all supported by the Phillips Laboratory, Directorate of Geophysics. A more detailed description and discussion of the physical models incorporated in CHIME, as well as a comparison between CHIME and other heavy ion models, is presented in a separate publication (Chenette, *et al.*, 1994b).

This Guide is in several sections. Section 2 presents a brief description of the physical models for the sources of energetic heavy ions, for the geomagnetic shielding calculation, and the method used to calculate the integral LET spectrum as incorporated in CHIME. This material was extracted from the original CHIME publication and presented here as a summary. More information is provided in the original publication, including references to and comparisons with other work. Section 3 of this document is a detailed description of the method used in CHIME for the single-event rate calculation, given the LET spectrum and the device cross-section for single-event effects.

Sections 4, 5 and on present information specific to the implementation of CHIME Version 3.5, on PC-compatible (MS/DOS) computer systems. Section 4 discusses installation of the software. Section 5 discusses how to run and use CHIME. Sections 6, 7, and 8 describe the formats and contents of CHIME input files, output files, and working files, respectively. All of the information in this document refers to CHIME Version 3.5. This was the first version of CHIME released for broad public distribution.

1

Previous versions were released for testing and to elicit comments from the user community. They should be discarded in favor of version 3.5.

## 1.2 Quickstart instructions

For those who do not want to be bothered by the details of the models or the methods used in CHIME, but just want to calculate some upset rates, follow these steps:

1. Install the software and data files according to the instructions in Section 4, or by running the batch file AINSTALL.BAT (or BINSTALL.BAT if the source disk is in drive B, rather than drive A). These files are provided on the distribution disk.

2. Consider and determine values for the parameters to be used to calculate the heavy ion flux model and the SEU rate calculation. See Section 5 for a list of the required input parameters.

3. Run the program and look at the results. To validate your installation, run the standard validation models and compare the results against those in the Appendix B. Output files from these validation runs also are provided on the distribution disk in the subdirectory named VALIDATE.

## 2. Model Components

### 2.1 Overview

The major components of the CRRES/SPACERAD Heavy Ion Model of the near-earth space Environment (CHIME) are indicated in Figure 1. The model covers the energy range from 10 MeV/nucleon to 60 GeV/nucleon for all known stable elements, and includes the known major sources of heavy ions in the near-earth interplanetary medium over this energy range, namely: galactic cosmic rays (GCR), the anomalous component (AC), and heavy ions from solar energetic particle events (SEP).

### 2.2 Galactic cosmic ray and anomalous component

The long-term time- and energy-variations of the galactic cosmic ray (GCR) and anomalous component (AC) heavy ions near earth are well understood as the result of "modulation" by the sun of a set of "local interstellar spectra" (LIS) defined at the outer boundary of the heliosphere. The amount of this modulation is described by a single parameter for all particle species: the solar modulation parameter, $\Phi$, which is in units of electric potential, typically megavolts (MV).

CHIME contains a comprehensive database describing the heavy ion flux environment near earth under the full range of expected solar modulation conditions. This database is a set of differential (in energy) heavy ion fluxes as a function of kinetic energy (E) and the solar modulation parameter ($\Phi$). The E, $\Phi$ range covered by this database is from 10 MeV/nucleon to 60 GeV/nucleon in kinetic energy and 300 MV through 1700 MV in solar modulation level. All ions from hydrogen (Z=1) through nickel (Z=28) are tabulated. Ions heavier than nickel are modeled using abundance ratios to iron. The abundance ratios of the elements heavier than nickel adopted for use in CHIME are documented in Table 1.

For the elements He, N, O, and Ne, an additional component, the anomalous component (AC), is also tabulated in the database. The AC was calculated using the same solar modulation code and for the same range of solar modulation as the galactic cosmic ray flux. Due to the nature of this source, however, the AC-LIS decrease very rapidly with increasing energy compared to the GCR-LIS. Thus the AC fluxes become insignificant compared to the GCR fluxes above a few hundred MeV per nucleon. Additionally, in the solar modulation calculation the AC was treated as singly charged, and the AC charge state is assumed to be 1 (singly charged) in the calculation of geomagnetic shielding, described below.

Both the GCR and AC fluxes are tabulated for values of E and $\Phi$ as necessary to insure that the interpolation error based on a cubic spline in log-log space is less than 1%.

3

# CHIME



Figure 1: CRRES/SPACERAD Heavy Ion Model of the near-earth space Environment module organization.

Table 1. Cosmic ray abundance ratios for elements heavier than nickel

| Atomic Number | Element Symbol | Abundance (Fe = 1,000,000) | Reference |
|---|---|---|---|
| 30 | Zn | 570.29 | Wefel (1988) |
| 32 | Ge | 89.38 | |
| 34 | Se | 71.39 | |
| 36 | Kr | 43.07 | |
| 38 | Sr | 34.40 | |
| 40 | Zr | 24.56 | |
| 42 | Mo | 17.53 | |
| 44 | Ru | 2.91 | |
| 46 | Pd | 5.70 | |
| 48 | Cd | 5.70 | |
| 50 | Sn | 5.70 | |
| 52 | Te | 7.14 | |
| 54 | Xe | 4.07 | |
| 56 | Ba | 7.14 | |
| 58 | Ce | 2.32 | |
| 60 | Nd | 2.32 | |
| 62 | Sm | 1.57 | |
| 64 | Gd | 2.08 | |
| 66 | Dy | 1.66 | |
| 68 | Er | 1.85 | |
| 70 | Yb | 1.06 | |
| 72 | Hf | 0.76 | |
| 74 | W | 0.84 | |
| 76 | Os | 0.95 | |
| 78 | Pt | 2.32 | |
| 80 | Hg | 1.48 | |
| 82 | Pb | 1.85 | Wefel (1988) |
| 84 | Po | 0.6 | estimate |
| 86 | Rn | 0.2 | estimate |
| 88 | Ra | 0.1 | estimate |
| 90 | Th | 0.05 | Cameron (1982) |
| 92 | U | 0.03 | Cameron (1982) |

Only even-Z element abundances have been measured reliably.
Odd-Z abundances are estimated equal to lower, even-Z abundance
this is probably a conservative over-estimate.

## 2.3 Solar modulation level and its variations

Given the database tabulation described above of the GCR and AC fluxes for the full range of levels of solar modulation, the actual environment appropriate to any specific time is defined by the solar modulation level at the orbit of earth, $\Phi(1AU,t)$. A model of the level of solar modulation as a function of time, tabulated monthly for the period from 1970 through 2010, is incorporated in CHIME. This model is adopted from historical data for the 20-year period from 1974 through 1993 (see Garcia-Muñoz, et al., 1985), and is based on a reasonable extrapolation, using a time-series analysis, beyond the times when data were available. This model captures several important features of the solar modulation process, including significant even/odd solar cycle effects in the duration and timing of solar activity minima and maxima. The model of solar modulation level vs time as incorporated into CHIME is shown in Figure 2.

To define a model environment due to GCR and AC fluxes, a user of CHIME may select either a time period or a specific level of solar modulation. If a time period is selected, CHIME computes the average of the fluxes for each ion species over the specified time period, using the tabulated monthly values of the solar modulation parameter (Figure 2). If a specific level of solar modulation is selected, CHIME computes the fluxes directly from the tabulation, interpolating, as necessary, as a function of $\Phi$.

To estimate a worst-case (highest flux intensity) GCR and AC model environment characteristic of solar minimum conditions, a solar modulation level of 450 MV is recommended. The opposite extreme, corresponding to solar maximum conditions, may be characterized by a modulation parameter in the range between 1200 and 1600 MV. CHIME will compute the GCR and AC heavy ion flux environment for any level of solar modulation from 250 to 1800 MV, inclusive, or as an alternative, using the model of Figure 2, for any time period from 1970 through 2010.

## 2.4 Solar energetic particle flux databases

In addition to the galactic cosmic ray and the anomalous component sources, which originate in regions well beyond the orbit of earth, the sun is a significant source of energetic heavy ions. These ions are injected into the near-earth interplanetary medium as a result of solar energetic particle (SEP) events. Several different SEP models are incorporated in CHIME. These include models based on measurements made during the CRRES mission and models based on statistical distributions of energetic solar proton event intensities. The user of CHIME may select any one of these models to add to the GCR and AC fluxes determined as described in the previous sections.

The two largest SEP events observed during the CRRES mission occurred in March and June 1991. Due to the significance of these events to CRRES investigations, they are made directly available for use in CHIME. The March event was an "iron-rich" event, but with a significantly softer energy spectrum than the June event (see Chen, et al., 1994, for a more detailed description of these events). Thus for very thin amounts

6
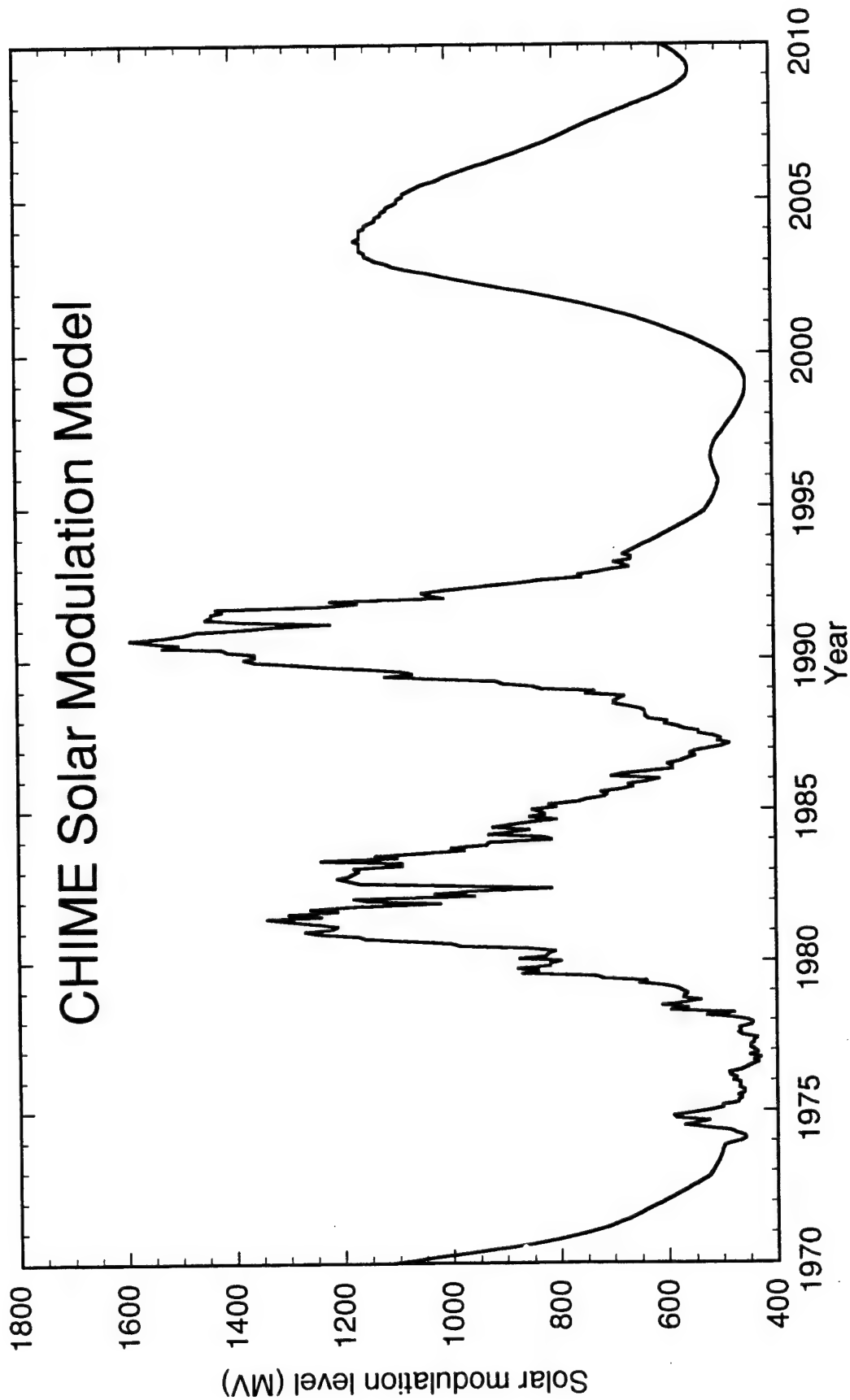
Figure 2: Monthly values of the level of solar modulation vs time as incorporated in CHIME. Maximum cosmic ray intensities occur at minimum solar modulation levels (e.g. 1975-7), and minimum cosmic ray intensities occur at maximum solar modulation levels (e.g. 1981-3 or 1991). Model values after 1994 and before 1974 are an extrapolation based on a time-series analysis of the 1974-94 period.

Table 2. Solar abundances used with the JPL 1991 model.

| Atomic Number | Element Symbol | Abundance (O = 100) |
|---|---|---|
| 1 | H | 1.17E+05 |
| 2 | He | 5.50E+03 |
| 3 | Li | 1.00E-06 |
| 4 | Be | 1.00E-06 |
| 5 | B | 1.00E-06 |
| 6 | C | 4.71E+01 |
| 7 | N | 1.28E+01 |
| 8 | O | 1.00E+02 |
| 9 | F | 1.00E-06 |
| 10 | Ne | 1.51E+01 |
| 11 | Na | 1.18E+00 |
| 12 | Mg | 2.03E+01 |
| 13 | Al | 1.40E+00 |
| 14 | Si | 1.55E+01 |
| 15 | P | 7.40E-02 |
| 16 | S | 3.56E+00 |
| 17 | Cl | 3.30E-02 |
| 18 | Ar | 3.30E-01 |
| 19 | K | 5.30E-02 |
| 20 | Ca | 1.20E+00 |
| 21 | Sc | 1.00E-06 |
| 22 | Ti | 6.10E-02 |
| 23 | V | 1.00E-06 |
| 24 | Cr | 2.30E-01 |
| 25 | Mn | 1.31E-01 |
| 26 | Fe | 1.55E+01 |
| 27 | Co | 3.13E-02 |
| 28 | Ni | 6.88E-01 |
| 29 | Cu | 6.25E-03 |
| 30 | Zn | 1.87E-02 |
| 31 | Ga | 6.25E-04 |
| 32 | Ge | 1.56E-03 |
| 33 | As | 9.38E-05 |
| 34 | Se | 9.38E-04 |
| 35 | Br | 1.25E-04 |

Table 2. Solar abundances used with the JPL 1991 model (continued).

| Atomic Number | Element Symbol | Abundance (O = 100) |
|---|---|---|
| 36 | Kr | 6.25E-04 |
| 37 | Rb | 9.38E-05 |
| 38 | Sr | 3.12E-04 |
| 39 | Y | 6.25E-05 |
| 40 | Zr | 1.56E-04 |
| 41 | Nb | 1.25E-05 |
| 42 | Mo | 6.25E-05 |
| 43 | Tc | 0.00E+00 |
| 44 | Ru | 2.81E-05 |
| 45 | Rh | 6.25E-06 |
| 46 | Pd | 1.87E-05 |
| 47 | Ag | 6.25E-06 |
| 48 | Cd | 2.19E-05 |
| 49 | In | 2.81E-06 |
| 50 | Sn | 6.25E-05 |
| 51 | Sb | 4.38E-06 |
| 52 | Te | 9.38E-05 |
| 53 | I | 1.87E-05 |
| 54 | Xe | 8.44E-05 |
| 55 | Cs | 6.25E-06 |
| 56 | Ba | 6.25E-05 |
| 57 | La | 6.25E-06 |
| 58 | Ce | 1.56E-05 |
| 59 | Pr | 2.50E-06 |
| 60 | Nd | 1.25E-05 |
| 61 | Pm | 0.00E+00 |
| 62 | Sm | 3.12E-06 |
| 63 | Eu | 1.25E-06 |
| 64 | Gd | 6.25E-06 |
| 65 | Tb | 9.38E-07 |
| 66 | Dy | 6.25E-06 |
| 67 | Ho | 1.25E-06 |
| 68 | Er | 3.12E-06 |
| 69 | Tm | 6.25E-07 |
| 70 | Yb | 2.81E-06 |

Table 2. Solar abundances used with the JPL 1991 model (continued).

| Atomic Number | Element Symbol | Abundance (O = 100) |
|---|---|---|
| 71 | Lu | 6.25E-07 |
| 72 | Hf | 2.50E-06 |
| 73 | Ta | 2.81E-07 |
| 74 | W | 3.12E-06 |
| 75 | Re | 6.25E-07 |
| 76 | Os | 9.37E-06 |
| 77 | Ir | 9.37E-06 |
| 78 | Pt | 1.87E-05 |
| 79 | Au | 3.12E-06 |
| 80 | Hg | 3.12E-06 |
| 81 | Tl | 2.81E-06 |
| 82 | Pb | 3.13E-05 |
| 83 | Bi | 1.88E-06 |
| 84 | Po | 0.00E+00 |
| 85 | At | 0.00E+00 |
| 86 | Rn | 0.00E+00 |
| 87 | Fr | 0.00E+00 |
| 88 | Ra | 0.00E+00 |
| 89 | Ac | 0.00E+00 |
| 90 | Th | 6.25E-07 |
| 91 | Pa | 0.00E+00 |
| 92 | U | 3.75E-07 |

of passive shielding, the March environment was more severe than that for June (Chenette, *et al.*, 1994a, b). The user can select the peak instantaneous flux or the highest 24-hour average flux for either event.

For predictive purposes CHIME also provides heavy ion fluence models as a function of mission duration and probability of occurrence. (In this context fluence refers to flux integrated over time.) These models are based on the "Interplanetary Proton Fluence Model: JPL 1991" (Feynman, *et al.*, 1993). This is a statistical description of the observed distribution of energetic solar proton event sizes. For a given mission start date and duration, the model provides a proton fluence spectrum which would be exceeded at a probability of occurrence, or confidence level, selected by the user (from 50% to 0.1%). Heavy ion fluences as a function of energy are scaled from the proton fluence spectrum using a table of energy independent, average solar energetic particle event, ion composition factors (Table 2).

It is important to remember that the JPL 1991 model describes ion fluences, which are fluxes integrated over a specific time interval. If a time interval is specified by the user in defining the GCR and AC fluxes, that same interval will be used in the SEP model if a JPL-based SEP model is selected. The fluences in the JPL 1991 model depend on the duration of the exposure (mission duration) in a way that is based on the statistical behavior of the SEP intensity distribution. They are not strictly proportional to the duration mission. Also in the JPL 1991 model, the 11-year solar activity cycle is divided into a 7-year active phase, where the results of the model apply, and a 4-year quiet phase, where no SEP events are anticipated. The active phase years of each 11-year solar cycle are 1977-1983, 1988-1994, 1999-2005,2010-2016, etc, inclusive.

The amount of the SEP contribution to the total ion fluence in any CHIME model environment will depend on the overlap between the time interval defined by the user and the active phase as defined in the JPL 1991 model (Feynman, *et al.*, 1993). For example, if a time interval is specified that is entirely within the quiet phase of the solar cycle, and one of the JPL 1991 models is selected, then there will be no SEP contribution in the final result. If the GCR and AC models are defined by the level of solar modulation, rather than a time interval, and one of the JPL 1991 models is selected, then the mission duration is taken to be one year during the active phase. The mission duration and "flare fluence coverage" intervals are documented in the flux output files produced by CHIME. The "flare fluence coverage" is the amount of time that the specified time interval overlaps the active phase of the cycle in the JPL 1991 model.

One consequence of these considerations that is implicit in the JPL model concerns mission durations greater than an entire solar cycle (11 years). Such models will be calculated by CHIME, but they will be only approximately correct in a statistical sense. The model produced by CHIME will be a linear extrapolation of the result for a 7-year active period to the total active phase duration of the model mission.

If one of the March or June 1991 SEP models is specified, the resulting ion fluxes are added to the GCR and AC fluxes without regard to the time period, interval, or phase of the solar cycle.

11

## 2.5 Geomagnetic shielding calculation

For earth-orbiting satellites at low altitude, both the earth's magnetic field and the solid earth itself provide significant additional protection from the interplanetary heavy ion environment. While the basic physical effect of the magnetic shielding is simply the Lorentz force on a moving charge, an exact calculation is complicated by the complex particle trajectories that can result, especially in the transition region where the magnetic field first begins to become transparent to the particles. A model for this effect is incorporated in CHIME. The model is based on an offset, tilted dipole approximation for earth's magnetic field. Despite its simplicity, this model captures the major features of the combined total average geomagnetic shielding effect with good accuracy.

Neglecting, for a moment, the shielding due to the solid earth, the earth's magnetic field produces an east-west asymmetry in the flux arriving at a observing location (defined by a magnetic radius r and latitude $\lambda$) such that for a dipole magnetic field, particles with a specific momentum per unit charge ($\rho = p/Q$) can only arrive within a cone of directions surrounding the west (for positive charges) with an angular extent $\omega$ given by

$$\cos(\omega) = 2Y/\cos(\lambda) - Y^2\cos(\lambda) \tag{1}$$

where $Y^2 = M/(c \, \rho \, r^2)$, M is the magnetic moment of the earth, and c is the speed of light. The solid angle corresponding to this cone is equal to $2\pi \, [1 + \cos(\omega)]$.

To account for the shielding due to the solid earth, the access cone solid angle is reduced by the fraction obscured by the earth at altitude h to obtain a total solid angle factor:

$$\Omega = \pi(1 + \cos\omega)\{1 + \cos(\arcsin(R_e / [R_e + h]))\} \tag{2}$$

This method is discussed in more detail in Wilson, *et al.* (1991). The vertical cutoff rigidity approximation often employed to estimate the geomagnetic shielding effect is a simplification of this procedure. It approximates the access function as a step function at the rigidity corresponding to a cone angle of 90°.

To incorporate the effects of this shielding, the user of CHIME may specify a location, an orbit, a partial orbit, or a series of orbits over some period of time. The GEOMAG Transmission function in CHIME calculates the access solid angle as a function of the ion energy and applies this filter function to the interplanetary heavy ion flux calculated by the procedures described in the previous sections. When an orbit is specified, this access filter is calculated as a time-weighted average at intervals as specified by the user. The transmission filter is applied separately to the GCR and AC spectra. While the GCR source is assumed to consist of fully stripped ions (Q = Z), the AC is treated as singly charged (Q=1) in this part of the calculation.

Beyond a radial distance of 100,000 km (about 15 earth radii) geomagnetic shielding does not have a significant effect on the ions in the energy range covered by CHIME. If either a location or an orbit with both the perigee and apogee greater than this is

specified, then the orbit calculation in CHIME is skipped, and the geomagnetic shielding effect is ignored.

## 2.6 Linear energy transfer spectrum calculator

For the purposes of estimating single-particle upset effects (including latchup), the heavy ion flux distributions as a function of particle type and energy are transformed into distributions as a function of the ion's linear energy transfer (LET). The LET is the energy lost by an ion and deposited into the target material per unit distance along the ion's path. LET generally increases with the atomic number of the ion (Z) and generally decreases with increasing velocity (V) approximately as $Z^2 V^{-2}$ (except at low and high velocities where atomic effects and relativistic effects, respectively, become important). Thus a faster iron ion and a slower oxygen ion can have the same LET and, by assumption, the same ability to produce a single event upset in a specific device. The LET spectrum is a convenient way to integrate and keep track of the contributions of the various ion species and energies, ordered according to LET.

The LET spectrum calculator in CHIME employs an integral method and a two-part (shield and target) spherical geometry model. The thicknesses of the shield and the target are specified by the user in one of several column density units: milligrams per square centimeter (mg cm$^{-2}$), mils of aluminum equivalent, or microns of silicon. Since the range of an ion depends on the density of the target and only weakly on the target composition, the mass density option (mg cm$^{-2}$) permits the model to be used with different materials, e.g. GaAs.

Working from the sensitive region out, and for each ion species, minimum and maximum incident ion energies are calculated corresponding to pre-defined LET thresholds. At each threshold LET, the integral LET spectrum is calculated by integrating the heavy ion flux spectrum over this energy range and summing over all particle species. The method and its results have been described in greater detail by Chenette, *et al.* (1994a).

In CHIME version 3.5, the LET spectrum is calculated both for the interplanetary flux environment model and for the near-earth flux distribution, shielded by the effects of the earth and its magnetic field. Either environment may be used to estimate single-event upset rates. Compared to the calculation based on the geomagnetically-shielded fluxes, the interplanetary model will always be a worst-case in the vicinity of earth, and it is useful for estimating worst-case instantaneous effects. In low earth orbit over the magnetic poles where the magnetic shielding is insignificant, the heavy ion flux is shielded only by the solid earth (and associated spacecraft structure). Thus the interplanetary flux intensity, reduced by the solid angle fraction obscured by the solid earth (less than a factor of 2) should be a good estimate of the instantaneous worst-case intensity in a low earth polar orbit. The shielded model should be a more accurate representation of orbit-average conditions near earth and should provide superior results for low altitude, low inclination orbits, or locations near earth and near the equator.

The abundances of the elements above zinc (Z = 30) in the periodic table are extremely low, yet this region represents over two-thirds of the total number of elements. Because these ions have such a low abundance, they often can be ignored unless one is interested in effects at LET values above 20 MeV mg$^{-1}$ cm$^2$. One portion of the LET spectrum calculation in CHIME depends on the number of different ion species. CHIME provides the user the option of ignoring elements in the periodic table above zinc (gallium to uranium, Z = 31 to 92) to speed up the calculation of the LET spectrum. This option should not be used for the most accurate results at high values of the LET threshold (LET values above 20 MeV mg$^{-1}$ cm$^2$).

## 2.7 Summary of LET spectrum calculation

The entire process necessary to define and calculate an LET spectrum using CHIME involves the following steps:
(1) define the cosmic ray and solar energetic particle environment model,
(2) define the orbit or location for the geomagnetic shielding calculation,
(3) apply the geomagnetic shield transmission function to the interplanetary spectra, and
(4) calculate the LET spectra based on these heavy ion flux environments.

This process is performed in one set of software modules which are invoked by selecting option 2 at the central CHIME user options selection screen (see Figure 3).

Within CHIME a model name refers to a specific environment. Once an environment and resulting LET spectrum are defined and calculated, that LET spectrum can be used to calculate single-event rates for a wide variety of different devices. The module used to perform this upset rate calculation in CHIME is described in the next section.

# CHIME Execution Flowchart



## User Options in CHIME

1. Select new model and/or change model parameters
2. Calculate new environment, orbit and LET spectra
3. Display or print spectrum, orbit, LET, or SEU files
4. Graphical screen display of model orbit or location
5. Calculate SEU rates using this environment
Q. Exit

(Options 3-5 are only available after completing option 2)

Start → Get new model name → Define model parameters

Calculate new model spectra

Output files:
<model>.ORB
<model>.SPC
<model>.LET

File Display and Print

Orbit Plotter

SEU Rate Calculator

Output file: <model>.SEU

Exit

15

Figure 3: The user controls model selection, calculation, and displays using the main CHIME option screen.

# 3. SINGLE-PARTICLE UPSET RATE CALCULATOR

## 3.1 Overview

To calculate a single-particle upset rate, CHIME combines the LET spectrum, calculated as described above, together with user specifications or measurements of the upset cross-section, and a model for the geometry for a specific device, and performs a numerical integration. This procedure incorporates a rectangular parallelepiped model like that of Pickel and Blandford (1980) to estimate the geometric factor of the sensitive region as a function of path length. It provides a way to allow the user to input a measured upset cross-section (as a function of LET) as an improvement on the "step function" approximation. The only restriction on this tabulation is that it must be monotonic non-decreasing with increasing LET. This method and its sensitivity to assumptions of the geometry model have been described by Shoga, *et al.* (1987). It is a direct application of a few simple geometrical concepts.

The upset rate is determined as the rate at which energetic heavy ions in the space radiation environment can deposit more than a certain minimum amount of energy into a specific volume. The minimum energy deposit required to cause an upset is called the upset threshold. The specific volume is the sensitive volume of a cell in the device. The single-particle upset rate is determined from the product of the local particle flux or fluence and the geometrical factor presented by the sensitive volume. The flux is in units of particles per unit solid angle, per unit area, and per unit time. The geometrical factor is in units of a solid angle, area product. In this context the fluence is the flux integrated over a specific time interval. Thus if a fluence is used in the calculation the result will be a total number of upsets rather than an upset rate.

The requirement to deposit more than a certain minimum amount of energy into a specific volume restricts the calculation. It leads to a specific method to organize the particle flux distribution and a specific method to describe the geometry of the sensitive region. This modified description of the particle flux distribution is called the linear energy transfer (LET) spectrum. The modified description of the geometry of the sensitive region is called the path length distribution.

## 3.2 LET spectrum

The linear energy transfer (LET) spectrum used in this calculation was described in the previous section. The integral form of the LET spectrum is used in CHIME. It represents the total flux (or fluence, the flux integrated over a mission duration) of particles of all types with an LET larger than some threshold (L). This spectrum is written as F(L).

## 3.3 Path length distribution

The amount of energy deposited in a sensitive volume determines whether or not the cell will be upset. The energy deposited by a particle with LET $L_0$ along path l is $E_D =$

16

$L_0*l$. Thus given the LET spectrum, the other information needed to establish the energy deposit is the length of the chord through the region (l) representing the track of the ion. This chord length (l, also known as a path length) is often multiplied by the density of the material being penetrated. As a result, the units of this path length can be expressed either in actual distance units (e.g. centimeters or microns), or in units of distance times mass per unit volume, which is mass per unit area (e.g. mg cm$^{-2}$).

Viewed from an arbitrary direction, any solid presents a distribution of chord lengths or projected thicknesses, over its projected area. This is the unidirectional path length distribution through the solid. It has a simple interpretation but can be rather complicated to express mathematically.

For any solid at an arbitrary orientation, there is an area, solid angle product (geometrical factor) presented by the solid for a given path length. In the present work, since the region of interest has an arbitrary orientation in space, the path length distribution is computed as the average over all orientations. The path length distribution is written P(l). It is zero for path lengths longer than the maximum chord through the volume ($l_{max}$). For the work reported here, the distribution is normalized so that the integral over all path lengths is equal to the total geometrical factor of the solid. For many types of solid prisms this is $\pi$ times the surface area of each face of the solid. For a right rectangular solid prism with dimensions x,y,z the path length distribution is written as P(l;x,y,z) and the normalization condition is:

$$\int_0^{l_{max}} P(l;x,y,z)\ dl = 2\pi(xy + xz + yz) \tag{3}$$

The maximum path length is given by:

$$l_{max} = \sqrt{x^2 + y^2 + z^2} \tag{4}$$

The form of the function P() is provided by Pickel and Blandford (1980), although they choose to use a different normalization than presented here.


## 3.4 Device geometry

Single-event upset susceptibility tests of microelectronic devices are often characterized by two parameters: a cross-sectional area of the device which is sensitive to upset, and a threshold value of the LET necessary to induce an upset. In the simplest idealization of the test results, the upset cross-section is zero below some threshold LET value, $L_C$, and a constant equal to some area, $A_U$, above this threshold.

The upset cross-section results yield to a simple geometric interpretation which has been validated by continuing device tests and analyses. The sensitive region of any cell, or bit of RAM, is often modeled as a rectangular solid section of the silicon chip. This section has a thickness (z) and some surface area (x*y). The geometric interpretation of the total sensitive area measured in the SEU tests is clear: For a

17

device with N cells (e.g. N bits in a RAM) the total sensitive area of the device is $A_U = N*x*y$. Thus, a measurement of the upset cross section together with a knowledge of the number of bits (N) yields an estimate of the sensitive cell area ($x*y$). The individual dimensions (x and y) can often be obtained with sufficient accuracy just as the square root of that area. More precise estimates are rarely required or justified. They must come from details of the manufacture of the device or from physical analysis of the structure.

The upset threshold value of the LET ($L_C$) multiplied by the thickness of the region (z) is interpreted as a minimum energy or charge deposit necessary to change the state of the device, $E_C = z*L_C$. (For silicon, this energy deposit or charge deposit are proportional to each other. The constant of proportionality is 3.6 eV/electron.) The thickness (z) is not generally known with great precision. It depends on parameters associated with the device technology and wafer processing. Fortunately, since both the test results and the real spectrum are expressed in terms of the LET, an imprecise knowledge of the depth (z) has little effect on the precision of the result. This has been demonstrated by detailed calculation (Shoga, *et al.*, 1988).

## 3.5 Total upset rate

The total upset rate (U) for the simple model outlined above is given by the following expression:

$$U = \int_0^{l_{max}} F(E_C / l) \, P(l;x,y,z) \, dl \tag{5}$$

The integral is performed over the entire path length distribution. However, for any path length, l, only particles with LET above the threshold $L = E_C / l$ contribute to the upset rate. Because the LET spectrum and the path length distribution are not simple analytic functions, the integral is generally computed numerically.

## 3.6 Integrating Detailed Upset Cross-Sections

The relatively simple integral described in the previous section is appropriate in the idealized situation where the measured upset cross section is a step function, equal to zero below some threshold value of the LET and equal to a constant value above it. The situation becomes slightly more complicated in the real world. In this section other shapes for the upset cross-section are addressed.

The upset cross-section measurements are rarely step-functions. More often, there is a transition region of LET where the cross-section rises from zero to some asymptotic value (Figure 4). This behavior has been discussed extensively in the literature and various explanations offered. For our purposes, however, we choose to adopt another simple concept to understand this effect. This concept also motivates and justifies our method to incorporate the effect into the calculation.

18

The concept to apply to the variation in upset cross-section with LET is to treat the ratio of the upset cross-section to its asymptotic value as an upset "effectiveness" or "efficiency". To accomplish this the upset cross section is divided by the area factor
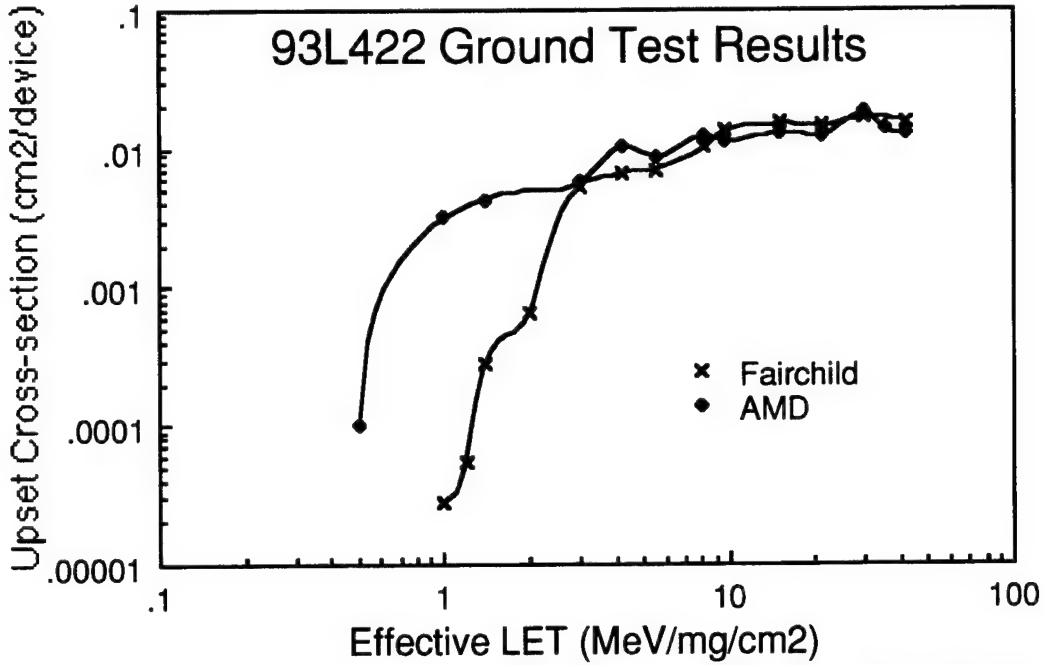


Figure 4: Measured single event upset cross sections for the 93L422 RAM

(x*y). At low values of the LET the efficiency for upset in the sensitive region is low. As the LET increases, the efficiency also increases. As the LET is increased still more an asymptotic cross section is established which defines the area sensitive to the SEU process. The upset cross-section divided by its asymptotic value is an efficiency in the range from 0 to 1. The area factor (x*y) is retained through the path length distribution normalization as in the discussion above.

In applying this concept to the integral necessary to calculate the SEU rate, the cross-section, renormalized as an efficiency, can be treated as a sum of step functions in the LET (h(L)) with amplitude $s_i$ at location $L_i$:

$$\varepsilon(L) = \frac{\sigma(L)}{x\,y} = \sum_i [s_i h(L_i) - s_{i-1} h(L_i)] \tag{6}$$

The subtraction is necessary to remove the contribution of one step function from the region to the right of the next. All of the values $s_i$ are in the range from 0 to 1 and monotonically increasing with increasing $L_i$. The sequence of values $s_i$ and $L_i$ can be chosen in many ways to approximate the shape of the upset cross section. Lower and upper limit estimates can be chosen and refined at will. An example is illustrated in Figure 5.
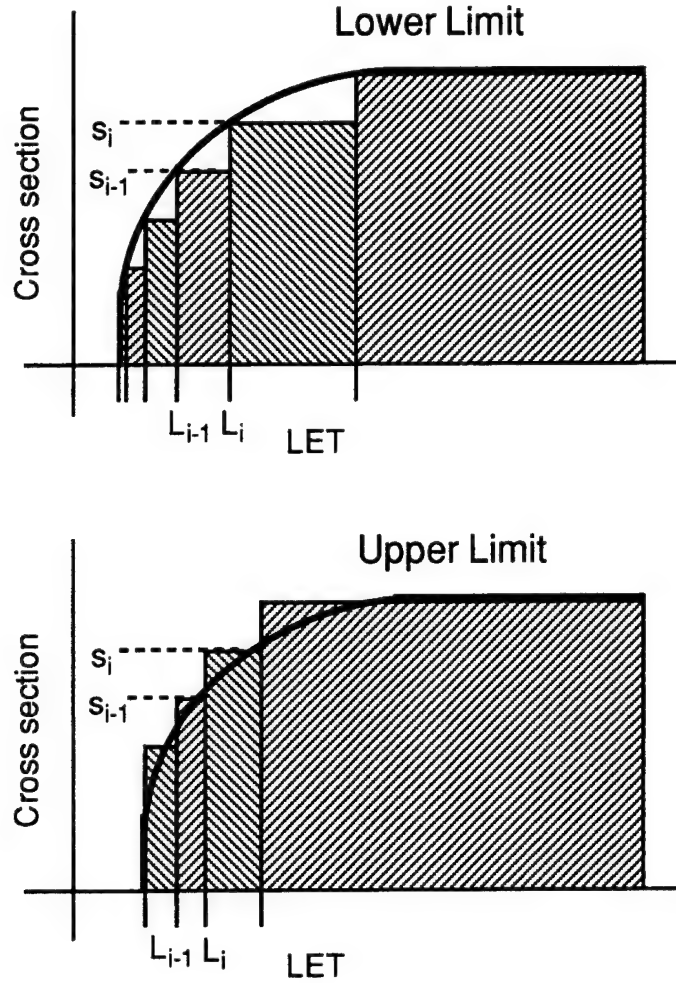
Figure 5: Step function approximations to the upset cross section

With this formulation of the measured upset cross section, the complete formula for the upset rate becomes:

$$U = \sum_i (s_i - s_{i-1}) \int_0^{l_{max}} F(z\, L_i\, /\, l)\, P(l;x,y,z)\, dl \qquad (7)$$

The factor $z^*L_i$ is the critical energy deposit threshold for each step function piece. This completes the presentation of the method.

## 3.7 Application of the method

Software to implement the method described in the previous section has been developed. A detailed description of the subroutines and listings of the source code are presented in the appendices. Some practical considerations for the use of this software are provided in this section.

Following the discussion above, there are four major components in the calculation. Each of these components must be provided. Most of them are input parameters or input data files. The major components are:

1. An estimate of the dimensions of the device cell which is sensitive to upset, modeled as a rectangular solid prism, and the number of sensitive regions in the device. The dimensions are labeled x, y, and z. By convention, the z dimension is normal to the face of the chip die. The area $A = x*y$ is the maximum total sensitive area of a unit cell (the sensitive area corresponding to a bit in a RAM, for example). N is the number of unit cells in the device. (The number of bits, for example.) The quantity $N*x*y$ should be equal to the asymptotic value of the upset cross section (part 3, below).

2. The distribution of path lengths through the sensitive region, P(l). The model provided in the code is for that of a solid rectangular prism.

3. The upset cross-section of the device as a function of LET, s(L). The cross-section is obtained from ground tests. Physically, to be consistent with the assumptions of the model, the upset cross section must be monotonically increasing with increasing LET. It is possible that the test results are not monotonic-non-decreasing with increasing LET. This is attributed to imperfections in the test results and the scatter around a smooth monotonic curve can be used as an estimate of the standard deviation of the test data set. The data set which is to be used in this software must be smoothed (by hand, if necessary) so that it is monotonic.

4. The flux of particles in the radiation environment as a function of LET, F(L). This distribution is calculated as described in the Section 2.

For each run, the upset rate is calculated three times, once each for a lower limit, an upper limit, and a central estimate. All of these estimates are controlled through the input cross section data file. Both upper and lower limits are defined with respect to the LET and cross section values provided in the file. In this calculation of the SEU rate, the step functions used for the lower and upper limit estimates are placed at the values of the LET which are provided in the input file. The lower limit model uses the cross section listed in the file at each LET. This yields a lower limit estimate as indicated by inspection of Figure 5. The upper limit model uses the cross section provided in the input file at the next higher value of the LET. This yields an upper limit estimate, again, as is clear from inspection of Figure 5. The central estimate is obtained by a 20-point linear interpolation of the listed cross section vs LET values. The effects of various uncertainties in the measured cross sections can be investigated by modifying the cross section data file. Different runs can be made with fewer entries in the cross section table or with the additional cross section values obtained by any of a variety of user-generated interpolation schemes.

Additional details of specific data formats and the mechanics of using the code are given in the following sections.

## 4. INSTALLATION INSTRUCTIONS

The CHIME data files and executable files must be properly located and arranged on a user's disk to enable the various portions of the code to work correctly. The file organization required by CHIME is shown in Figure 6. The following instructions will accomplish this:

1. Select the location (disk drive and directory) where you wish to install CHIME and make a subdirectory there called CHIME. (You may choose a different name for this directory, if you wish. If you use a different name, you must adjust the following instructions as appropriate.)

2. Inside the CHIME directory, make a subdirectory named FLUXES.

3. Copy the contents of the FLUXES directory from the distribution floppy disk to the FLUXES directory created in step 2. The following files should be copied:
   SXXX.DAT      with XXX equal to 300, 350, ..., 650, 700 (300 to 700 by 50)
   SYYY.DAT      with YYY equal to 800, 900, ..., 1700 (800 to 1700 by 100)
   SXXXA.DAT     with XXX equal to 300, 325, ..., 675, 700 (300 to 700 by 25)
   SYYYA.DAT     with YYY equal to 750, 800, ..., 1650, 1700 (750 to 1700 by 50)
   FEYNDTBL.DAT

4. Copy all of the executable files from the distribution floppy to the CHIME directory. The following files should be copied:
   CHIME.EXE
   CRRESCRM.EXE
   SPCSHOW.EXE
   PLOTORB.EXE
   SEUCALPC.EXE

5. Copy the two font files, OEM08.FON and ROMAN.FON, to the CHIME directory.

6. Copy the five page files, PAGE0.CHI, ..., PAGE4.CHI, to the CHIME directory.

7. To run CHIME, move to the CHIME directory (e.g. the DOS command CD CHIME) and execute the program (e.g. type CHIME in DOS).

8. All output files will be made in the CHIME directory. CHIME will request a model name from the user when defining the parameters for a new run. All of the output files produced by CHIME for a given run will share this name, but will have different filename extensions.

Two batch files have been provided on the distribution disk that will install the CHIME subdirectory and all of the required files in a subdirectory selected by the user. Use the batch file named AINSTALL.BAT to install CHIME if the source diskette is in your A: drive or the file BINSTALL.BAT to install it from a source diskette in the B: drive.

Parent Directory (or subdirectory).  Recommended name: CHIME

| | |
|---|---|
| CHIME.EXE | user interface and main CHIME entry module |
| CRRESCRM.EXE | environment and spectrum calculator module |
| SPCSHOW.EXE | module to display flux, LET spectrum, and orbit listings |
| PLOTORB.EXE | module to plot orbit model |
| SEUCALPC.EXE | module to calculate upset rates from device information |

PAGE0.CHI
PAGE1.CHI
PAGE2.CHI         information screens (see Appendix A)
PAGE3.CHI
PAGE4.CHI

OEM08.FON         font files for orbit plot module
ROMAN.FON

All output files generated by CHIME will be written into this directory

[FLUXES]      Subdirectory of main CHIME directory.  It must be named FLUXES
    FEYNDTBL.DAT     data file for JPL 1991 solar particle fluence model
    SXXX.DAT      with XXX equal to 300, 350, ..., 700 (300 to 700 by 50)
    SYYY.DAT      with YYY equal to 800, 900, ..., 1700 (800 to 1700 by 100)
    SXXXA.DAT     with XXX equal to 300, 325, ..., 700 (300 to 700 by 25)
    SYYYA.DAT     with YYY equal to 750, 800, ..., 1700 (750 to 1700 by 50)

Figure 6.  The file organization required to run CHIME Version 3.5 for MS/DOS.

# CHIME Spectra

Data Files | Programs and Processes | User Inputs
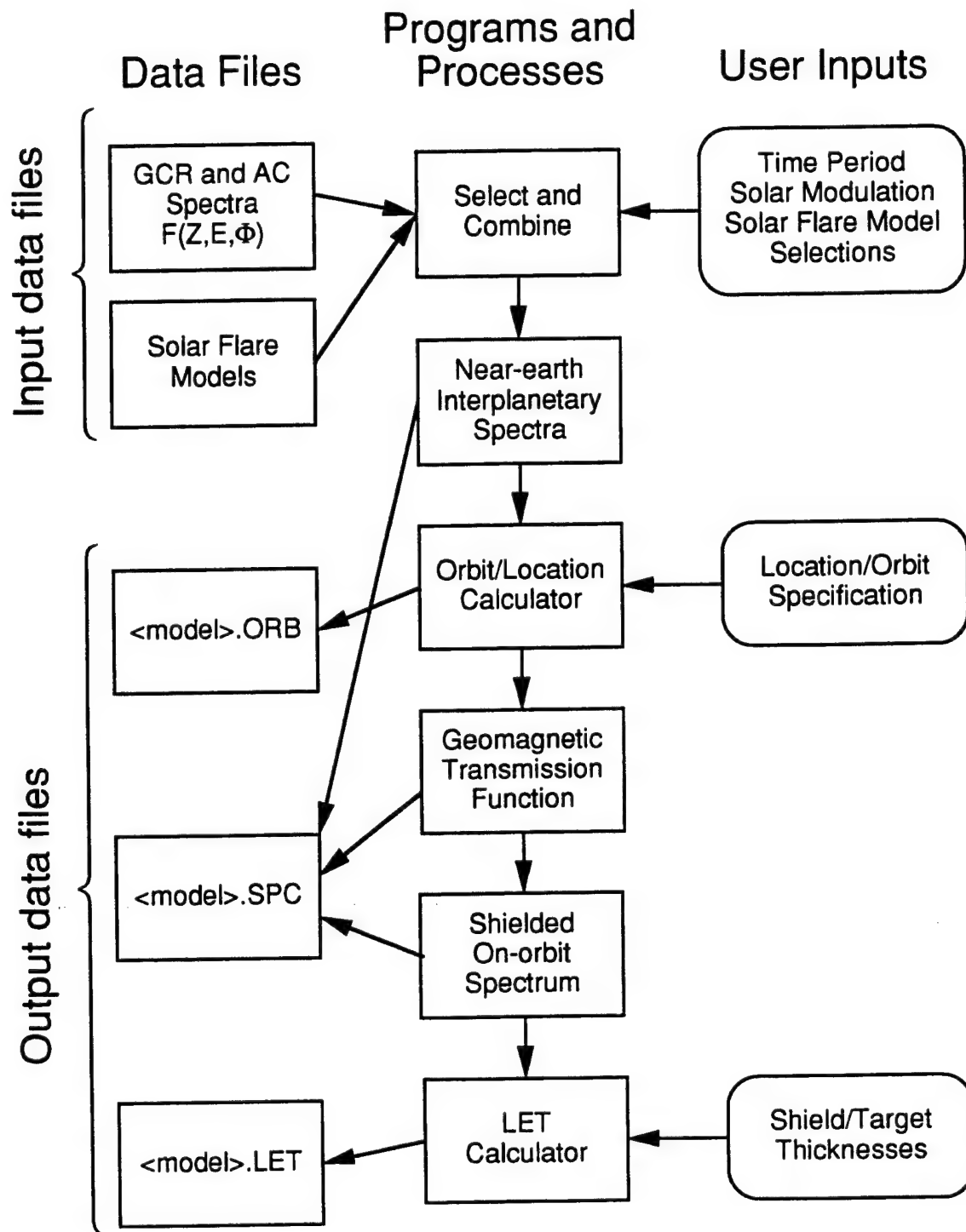


Figure 7: Flowchart for Environment Spectrum Calculator

24

## 5. OPERATING INSTRUCTIONS AND INPUT PARAMETER LIST SUMMARY

Once the CHIME software has been installed according to the instructions above in Section 4, CHIME can be executed. A flowchart illustrating how the user controls the execution of CHIME was provided in Figure 3. A more detailed view of the process used to calculate a model environment and LET spectrum is shown in Figure 7.

Many different heavy ion flux environments and LET spectrum models can be computed and maintained within CHIME so that single event effects for a wide variety of devices can be calculated for many different models. Each flux environment model is defined and organized by a user-supplied model name of up to 8 characters. This name is used as the file name for all of the files associated with a specific model. When a model is defined with a new name, CHIME records the date and time, which also serve to identify the run. CHIME also prompts the user to enter two lines of text describing each model. These text lines may be used for any purpose. They will be copied to all of the output files for the model.

Before executing CHIME it may be useful to consider in advance the values to be entered for the required input and control parameters. A summary of these parameters is provided here together with a brief discussion of appropriate ranges and other related considerations.

The following five sets of parameters are necessary to define a heavy ion flux environment model. The results of such a model will be both particle flux and LET spectra. Additionally, a sixth set of parameters must be provided, describing the susceptibility of a microelectronic device to single particle effects, to estimate a single particle upset rate for that device.

1. Choose a meaningful model name for the CHIME result files.

This model name is limited to 8 characters, and including only those characters acceptable in DOS file names. When a model specification is completed, CHIME will assign to the model a creation date and time. The user also may enter up to two lines of text to describe the model. These text lines will be written to all of the output files associated with this model run. They also are displayed to the user when selecting a model from among those already available.

2. Choose the method and manner of specifying the level of solar modulation.

For the highest-fidelity model of average galactic cosmic ray intensity during any period from 1974 through 1993, or to calculate a realistic model for some future time period, select the period method (P) and specify the year and day of year

Table 3.  Solar Flare Energetic Particle Flux Models in CHIME

| Index | Model description |
|-------|-------------------|
| 0 | No solar flare heavy ion enhancement included. |
| 1 | March 1991 solar flare peak flux environment. |
| 2 | June 1991 solar flare peak flux environment. |
| 3 | March 1991 solar flare 24-hour average flux environment. |
| 4 | June 1991 solar flare 24-hour average flux environment. |
| 9 | JPL 1991 Solar Flare Fluence Model (Feynman, *et al.*, 1993). |

Table 4.  Probability level indices for the JPL 1991 model

| Index | Probability that model fluence would be exceeded in an actual mission |
|-------|-------------------|
| 1 | 50.0 % |
| 2 | 20.0 % |
| 3 | 10.0 % |
| 4 | 5.0 % |
| 5 | 2.0 % |
| 6 | 1.0 % |
| 7 | 0.5 % |
| 8 | 0.2 % |
| 9 | 0.1 % |

corresponding to the beginning and end of the period of interest. CHIME tabulates solar modulation monthly, since the average solar modulation level changes relatively slowly with time. For a "typical worst-case", highest galactic cosmic ray flux intensity corresponding to solar minimum conditions, select the modulation level method (M) and input a level of solar modulation of 450 MV or less (see Figure 2).

For a minimum intensity galactic cosmic ray flux model corresponding to solar maximum conditions, select the modulation level method (M) and input a level of solar modulation of 1200 MV to 1500 MV or more (Figure 2).

3. Choose the solar flare energetic particle model to add to the GCR model.

The various models available in CHIME are listed in Table 3. For the JPL 1991 model, a probability level must also be defined (see Table 4). This is the probability that the model flux would be exceeded during a mission at the time and of the duration specified in step 2.

Since the JPL 1991 model describes integrated mission fluences, if this model is selected, then the galactic cosmic ray and anomalous component fluxes are also converted to total mission fluences, and the flux models and LET spectra are time-integrated. SEU calculations based on these spectra will have units of total upsets (for the entire model mission), not upsets per unit time. If a level of solar modulation (rather than a specific time period) is provided in step 2, CHIME will use a nominal mission duration of 1 year during solar active conditions.

4. Determine the orbit parameters or select a location in space for the flux calculation.

Since the geomagnetic transmission function depends on magnetic latitude and distance, the location or orbit are computed in earth-fixed (co-rotating) coordinates. The Cartesian axes of this coordinate system have Z along earth's rotation axis, positive north, and X in the equatorial plane towards the prime meridian. If a specific location is desired, it is specified by a distance (either altitude in kilometers, or radial distance in earth radii), and a geographic latitude and longitude. If an orbit is defined, the following orbital elements must be provided:

> perigee and apogee altitudes (from the earth's surface), in kilometers
> the argument of perigee, inclination, and right ascension of the ascending node, in degrees
> the start day of year (1-366) and the time of perigee in seconds of the day
> the start time, end time, and time step for the orbit integration, in seconds
>> [If the end time is specified as a negative number, the orbit will be integrated for a number of whole orbits equal to -int(end time)].

27

5. Define the shield and target thicknesses for the LET spectrum calculation.

The shield and target thicknesses may be provided in units of milligrams per square centimeter, mils of aluminum (most appropriate, perhaps for the shield), or microns of silicon (perhaps most appropriate for the sensitive region thickness). Since the final spectrum is expressed in LET, that is, per unit thickness of the sensitive region, the result is not very sensitive to this thickness, as long as it is much thinner than the shield. A nominal sensitive region thickness of 1 micron may be adopted for this part of the calculation without serious error or impact on subsequent single event rate estimates.

While CHIME will calculate LET spectra for any thickness of passive shielding, unrealistically thin shields may not give realistic results when solar energetic particle event models are included. This will be a concern only when calculating models which include SEP events because the lowest-energy GCR and AC flux intensities decrease with decreasing energy. If a shield thickness less than 20 milligrams per square centimeter, or 4 mils of aluminum, or 100 microns of silicon is specified by the user, CHIME will display a warning. This thickness corresponds approximately to the range of a nickel ion with an energy of about 10 MeV/nucleon, or to the range of a 3 MeV proton.

CHIME does not account for the effects of nuclear interactions in the shield or the target. For the thickest shields, if these nuclear interactions were taken into account they would tend to soften the LET spectrum, that is, there would be relatively more flux at lower LET and somewhat less at higher LET.


6. If you wish to calculate an upset rate, decide how to describe the device.

Finally, as discussed in Section 3, certain parameters describing the single-particle susceptibility are required to calculate an SEU rate for a specific microelectronic device. CHIME is structured so that many different environments may be calculated and applied to the upset rate calculation for a single device, and many different device models may be used to estimate SEU rates in each environment. The required format and contents of the device file (.DEV) are described in the following section 6.1.

CHIME can also calculate SEU rates based on a user specification of LET threshold and upset cross-section (step-function approximation to the cross-section). If this latter method is used the following input parameters must be entered at run time:

> LET threshold in MeV mg$^{-1}$ cm$^2$   MeV/(mg/cm$^2$)
> Upset cross section in cm$^2$ for the device
> Number of sensitive regions
> X (chip face) dimension of a typical sensitive region in microns
> Y (chip face) dimension of a typical sensitive region in microns
> Z (depth) dimension of a typical sensitive region in microns
> Density of sensitive region material in mg cm$^{-3}$ (e.g. 2330 for silicon)

## 6. INPUT FILES AND FORMATS

In addition to the information provided by the user to CHIME at run time as described in the previous section, CHIME may be controlled, in part, by information provided in either or both of two other input files. These files are called the device file, and the settings file. The structure and format of these files is described in this section. Neither of these files is required to execute CHIME, both are optional.

The device file contains single-event susceptibility data for a specific microelectronic device. It is used only in the final section of CHIME devoted to the SEU rate calculation. Heavy ion environment particle flux spectra and LET spectra can be calculated independent of the device file. Many different devices can be run through the same environment and many different environments can be run on the same device in this way. If the device susceptibility is described simply in terms of an upset LET threshold and upset cross-section (or sensitive area), then these two parameters can be entered at run time and no device file is required.

The settings file can be used to customize certain features and characteristics of the CHIME output files as well as the appearance of CHIME displays on the screen. The settings file must be named "CHIMESET.SET", and it must appear in the same directory as CHIME.EXE, otherwise it will be ignored.

### 6.1 Device file:   <device name>.DEV

This file describes the single-particle upset susceptibility of a specific microelectronic device. The file may be either a listing of the SEU cross-section of a specific device, or a more simplified LET threshold and sensitive area (see Section 3). The name of this file is arbitrary, except that it must have the DOS file extension ".DEV"

There are five sets of key strings which must appear in the file, and one key string that is optional. The optional key string is the eight-character sequence "DENSITY=". The first four required key strings are the two-character sequences:  "X=", "Y=", "Z=", and "N=". The last required key is the three-character string "LET". Each of the "DENSITY=", "X=", "Y=", "Z=", and "N=" key strings must be followed immediately (except for optional blank spaces and tabs) by a numeric value. This value is interpreted and assigned to the respective variable.

The "DENSITY=" key string provides an optional method to specify a material other than silicon for the sensitive region. If this string appears, the corresponding value is interpreted as the density of the sensitive region in units of  mg cm$^{-3}$. If this string is not present in the device file a value of 2330 is assumed, which is appropriate for silicon.

The first three required key strings describe the physical characteristics of a typical sensitive region in the device. X, Y, and Z are the dimensions of the typical (or average) sensitive region cell in microns. The Z dimension is assumed to correspond to depth. The quantity X*Y is the sensitive surface area of a single cell.

The number of sensitive volumes in the device cross-section table is defined by the value of fourth required key string parameter, N. If the cross-section is tabulated in the device file in units of "per bit", N should be set to 1 (e.g. "N= 1").

Any number of lines of text may begin the file (these should include the "X=", "Y=", "Z=", and "N=" key strings) as long as the sequence "LET" is not present. The first line containing the three characters "LET" is assumed to be a comment line. It is copied to the output as partial documentation of the run. Following this comment line must be a series of lines, each containing two values, as in a two-column tabular form. This is the tabulation of the device upset cross-section. The first value on each line must be the LET in units of MeV per milligram per square centimeter. The second value must be the device upset cross-section corresponding to that value of the LET in units of square centimeters per device (or square centimeters per bit if the number of bits is set to 1). As discussed in section x.x, the cross-section as atbulated in this file must be a monotonic non-decreasing function of the LET. A maximum of 50 entries in the device upset cross-section table is supported. Sample device upset cross-section files are provided on the distribution disk in the subdirectory named DEVICES. Examples also are listed in Appendix B.

## 6.2 Settings file:  CHIMESET.SET

This file provides the user with the option to control some of the execution and output parameters of the CHIME program. If this file exists in the same directory as the executables, then the file will be read for any of the following key words. Each key word is 5 characters long and must appear exactly as shown, all in upper case, to be recognized by the program. If one of the key words listed below is found in this file, then the number immediately following the key word will be used to determine the value of the corresponding parameter when the program is executed. The keyword and number may be separated by one or more spaces. Any other text in the file is ignored as a comment. If a keyword appears more than once, only the last value will be used. The following keywords are defined. They may appear in the file in any order. More than one keyword may appear on a line.

ZMINP - the minimum atomic number to print out in the spectrum listing file.
    Default value: 1    Acceptable range: 1 through 28
ZMAXP - the maximum atomic number to print out in the spectrum listing file
    Default value: 28    Acceptable range: ZMINP through 28
DELZP - the number of atomic number steps between ions in spectrum listings
    Default value: 1    Acceptable range: 1 through 1000
DELEP - the number of energy steps between lines printed in the spectrum listing
    Default value: 4    Acceptable range: 1 through 1000
LETMN - the minimum LET to calculate for the LET spectrum in MeV mg$^{-1}$ cm$^2$
    Default value: 0.01    Acceptable range: 0.001 through 100.0
LETMX - the maximum LET to calculate for the LET spectrum in MeV mg$^{-1}$ cm$^2$
    Default value: 100.0    Acceptable range: LETMN through 100.0
NLETS - the number of LET values to tabulate from LETMN to LETMX
    Default value: 50    Acceptable range: 2 through 100
CBACK - the color of the screen background (default blue)

Default value: 1    Acceptable range: 0 through 15
CTEXT - the color of the screen text (default white)
Default value: 7    Acceptable range: 0 through 31
CNTRY - the color of entry text (default yellow)
Default value: 14    Acceptable range: 0 through 31
CWARN - the color of warning text (default light red)
Default value: 12    Acceptable range: 0 through 31
CCONV - controls the convergence requirement for the SEU rate integral
Default value: 0 (prompt at run time)    Acceptable range: 0 - 3 (3 = high)

For example, as a CHIMESET.SET file, the following lines of text would direct CHIME to print energy spectra only for carbon, oxygen, and neon (Z = 6, 8, and 10), and to calculate a 10-point LET spectrum from 0.01 to 30.0 MeV mg$^{-1}$ cm$^2$:

```
This and the next 4 lines are one example of a possible CHIMESET.SET file
ZMAXP 10  maximum atomic number to print is 10, corresponding to neon
ZMINP6  minimum atomic number to print is 6, carbon (no space required)
DELZP 2  LETMX 30.0   print every other Z, maximum LET is 30 MeV/mg/cm2
NLETS 10  Calculate and print the integral LET spectrum at 10 LET values
```

The output LET spectrum is always calculated including all ion species from Z=1 to Z=92 (or only to Z=30 if the "quicker" calculation method is selected by the user, as described elsewhere), and the particle flux spectra are calculated using the highest available energy resolution, regardless of the settings of these parameters. The LET spectrum is calculated and printed out only over the range defined by LETMN and LETMX in NLETS steps that differ by a constant multiplying factor (equal steps in log(LET)). See Table 5 for the values to enter for color variables. An example CHIMESET.SET file is provided on the distribution disk in the DOCS subdirectory.

Table 5.  Color selection table for the CHIMESET.SET file

| Value | Color |
|-------|-------|
| 1 | black |
| 2 | blue |
| 3 | green |
| 4 | cyan |
| 5 | red |
| 6 | magenta |
| 7 | brown |
| 8 | white |
| 9 | dark gray |
| 10 | light blue |
| 11 | light green |
| 12 | light red |
| 13 | light magenta |
| 14 | yellow |
| 15 | bright white |

Values in the range 16-31 are the same colors as
those in the range 0-15, but with blinking text.

31

## 7. OUTPUT FILES AND FORMATS

Most of the output files for any run of CHIME are identified according to a model name provided by the user. Any string of up to 8 characters legal for use in DOS file names may be specified when prompted by the program. Once a model name has been chosen, it will be used as the default until the user enters a new name. In the following section, the current model name is identified as <model>.

### 7.1 The particle spectrum output file: <model>.SPC

This is as ASCII file containing output tables of particle energy spectra and the geomagnetic transmission as a function of rigidity, corresponding to the model parameters selected by the user. The file is in three major sections, each of which is broken-up into sub-sections for ease of display on a screen. At the front of each section information is provided to document the parameters corresponding to the model as selected by the user.

The first major section of the .SPC file is a detailed listing of the differential flux or fluence of each ion as a function of the ion kinetic energy in MeV per nucleon, as it would be measured near the orbit of earth, but at a sufficiently large distance that the geomagnetic and solid-earth shielding effects can be ignored. The anomalous component is tabulated separately at the end, following the combined listing of cosmic ray and (optionally) solar energetic ions.

The second major section of this file is a tabulation of the average geomagnetic transmission function for the location or orbit specified by the user. The value of this function varies from 0 (complete shielding) to 1 (perfect transmission, no shielding effect) as a function of rigidity (ion momentum per unit charge). This is an directionally-averaged result.

The final section of the .SPC file is another detailed listing of the differential flux or fluence of each ion as a function of the ion kinetic energy in MeV per nucleon. This tabulation differs from the first one in that the effects of the geomagnetic transmission have been applied to the spectra. The anomalous component is tabulated separately at the end, following the combined listing of cosmic ray and (optionally) solar energetic ions.

### 7.2 The orbit position listing output file: <model>.ORB

This is an ASCII file which documents the user's selection of the location or orbit to be used in the geomagnetic shielding calculation. The file also includes a listing of the earth-fixed coordinates at each time step used in the calculation. The orbit plot is generated from this listing. The coordinate system is earth-centered and earth-fixed (co-rotating) with Z along the earth's rotation axis and X towards the intersection of the

equator and the prime meridian. In this listing, the radial distance (and the X, Y, and Z coordinates) are all taken with respect to the center of the earth.

### 7.3 The LET spectrum listing output file:   <model>.LET

This is an ASCII file listing of the calculated LET spectrum. It is based on the particle flux or fluence spectra listed in the third section of the .SPC file (after the geomagnetic shielding calculation). This file also documents the shield and target thicknesses selected by the user for the LET spectrum calculation and (for example) whether or not the trans-iron elements (Z>30) were included in the calculation.

### 7.4 The SEU rate calculation output file:   <model>.SEU

This is an ASCII file listing of the single-particle upset rate calculation results. A new section is added to this file whenever the model is used to calculate an SEU rate. For reference, the file documents the input LET spectrum and the device characteristics (upset cross-section, dimensions, etc.) provided either by direct input or in the device file (.DEV). The upset rates calculated for the device from both of the model LET spectra (interplanetary and geomagnetically-shielded) are listed at the end of each section. Sections are separated by rows of asterisks (*******************************).

### 7.5 The model parameter output file:   <model>.CHM

This file contains all of the user input parameters for a run of CHIME. It is useful for documenting the characteristics of an environment model. CHIME can only recognize a previously-run environment if this file exists together with the .SPC, .ORB, and .LET files in the CHIME directory. (In contrast, the .SEU file is produced only when an upset rate is calculated. It is not considered to be part of an environment model.) However, if only the .CHM file exists, CHIME can recalculate the .SPC, .ORB, and .LET files.

This file consists of nine lines of ASCII text. The format and content of each line are:

> Line 1:  The model name (1 to 8 characters acceptable in file names).
>
> Line 2:  The date and time when the model was defined (ASCII).
>
> Lines 3 and 4:  Two lines of text describing the model. These lines are entered by the user when a new model is defined.
>
> Line 5:  A single character, either P or M, for Period or Modulation level.

33

Line 6: Four integer values, each separated by one or more spaces. If the character in line 5 is a P, then line 6 must contain a start year, start day, end year, and end day for the period corresponding to the requested environment model. Values for the years must be between 1970 and 2020 (inclusive). Values for the days must be between 1 and 366 (inclusive). If the character in line 5 is an M, then the contents of this line must still appear, but they are ignored. For example, 0 0 0 0 would be acceptable for line 6 if line 5 is an M.

Line 7: Four integer values, each separated by one or more spaces. The first value on this line is the solar modulation level to be used if the character on line 5 is an M. (If line 5 is a P, this value is ignored, but some number must still be present.) The second value is the index of the solar flare energetic particle model as listed in Table 3 (0-4 or 9). The third number is the probability level index for the JPL 1991 model, as listed in Table 4 (1-9). The probability level index is ignored unless the value of the first number on this line is 9, but some value must always be provided, if only as a place-holder. The fourth value on this line is the day of year corresponding to the time for the orbit calculation (1-366).

Line 8: Nine floating point values, each separated by one or more spaces. The nine values on this line, in order, must be either an orbit specification, as:
1. Perigee altitude, in kilometers.
2. Apogee altitude, in kilometers.
3. Argument of perigee, in degrees.
4. Orbit inclination, in degrees.
5. Right ascension of the ascending node of the orbit, in degrees.
6. The time of perigee, in seconds of the day.
7. Start time for the orbit integration, in seconds of the day.
8. End time for the orbit integration, in seconds of the day.
9. Time step for the orbit integration, in seconds.
OR If the first value on this line is -0.5 or -2.0, a single location is defined:
1. A flag value: -0.5 for altitude in km or -2.0 for radius in earth radii.
2. Altitude in kilometers or Radius in earth radii (depending on item 1).
3. Latitude, in degrees.
4. Longitude, in degrees.
5. ignored.
6. ignored.
7. ignored.
8. ignored.
9. ignored.

Line 9: Two floating point values, two integers, and a single character, each separated by a single space, to define the LET spectrum calculation. These five parameters, in order, must be:
1. Shield thickness in the units defined by item 3
2. Sensitive region thickness in the units defined by item 4
3. 1, 2, or 3, to define the units of the shield thickness, as:
      1 -> shield thickness is in milligrams per square centimeter
      2 -> shield thickness is in mils of aluminum
      3 -> shield thickness is in microns of silicon
4. 1, 2, or 3, to define the units of the sensitive region thickness
5. A single character, separated from the previous value by one space. If this character is N, then the LET spectrum will not include elements with atomic number greater than 30. This speeds up the calculation by about a factor of 3 and affects the intensity of the LET spectrum at only the highest LET values, where the flux is extremely low.

## 7.6 The CHIME parameter file: CHIME.PAR

This file is used only for internal module-to-module communications to store the model name and some screen information. It is described in more detail in section 8.3. The user need not be concerned with this file unless it is corrupted or otherwise suspected as a possible source of some unanticipated problem. If this file is not found in the same directory as the CHIME.EXE program when CHIME.exe is invoked, a new CHIME.PAR file will be generated automatically. If this file should ever become damaged or corrupted CHIME may not function properly. In such a case the user may safely delete or rename this file as long as CHIME is not active, executing, or loaded in memory.

# 8. CHIME EXECUTABLE, INFORMATION, AND DATA FILES

## 8.1 Executable files:

CHIME.EXE
This is the main executable. It includes the module which prompts for input from the user and it provides links to the other modules of the CHIME package.

CRRESCRM.EXE
This is the module which calculates the flux environment model energy spectra and the LET spectrum from the user inputs provided in CHIME.EXE.

PLOTORB.EXE
This is the module which provides the graphical view of the orbit selected by the user for the geomagnetic shielding calculation.

SPCSHOW.EXE
This is the module which displays to the screen and/or prints out the contents of the output listing files produced in CHIME: <model>.SPC, <model>.ORB, <model>.LET, or <model>.SEU.

SEUCALPC.EXE
This is the module which takes the LET spectrum tabulated in the <model>.LET file together with the device model tabulated in <device>.DEV file and calculates the rate or number of single-event upsets expected for the device in the specified environment. Results are written to the <model>.SEU output file.

## 8.2 Data files (contents of the FLUXES subdirectory):

SXXX.DAT
These are the files containing the compressed galactic cosmic ray flux spectra as a function of atomic number (Z) and kinetic energy (E). Each file contains all Z and E corresponding to a specific level of solar modulation. The solar modulation level is coded in the file name as the XXX value (in MV). The files are in ASCII format and the rows and columns of information are labeled in each file. Any of these files may be viewed in a suitable text processor or spreadsheet program. However, care should be taken to insure that the format and contents of each file are preserved and not modified in any way. The flux values in each file are base 10 logarithms of the differential particle flux in units of particles per square meter, second, steradian, MeV per nucleon.

SXXXA.DAT
These are the files containing the compressed anomalous component flux spectra as a function of atomic number (Z) and kinetic energy (E). Each file contains all Z and E corresponding to a specific level of solar modulation. The solar modulation level is coded in the file name as the XXX value (in MV). The files are in ASCII format and the

rows and columns of information are labeled in each file. Any of these files may be viewed in a suitable text processor or spreadsheet program. However, care should be taken to insure that the format and contents of each file are preserved and not modified in any way. The flux values in each file are base 10 logarithms of the differential particle flux in units of particles per square meter, second, steradian, MeV per nucleon.

FEYNDTBL.DAT
This file contains lists of coefficients used to implement the JPL 1991 model of solar energetic particle fluence spectra in CHIME.


## 8.3 Other support files:

CHIME.PAR
This file is used to document the name and date of the active flux environment model. It is used internally to coordinate the calculation, display, and plotting modules in CHIME so that they all refer to the same model. The file contains two lines in ASCII format. The first is the model name, and the second is the date and time when the model was created. If this file exists, the model named here will be assumed as the default model. If the file does not exist, the CHIME program will prompt the user for a new model name (TEST is the default new name). When a new model name is selected, all of the parameters necessary to define a new environment, including a new orbit file, and target and shield thicknesses, will be requested. The program will then also calculate and output particle flux spectra, orbit, and LET spectra files for the new model.

PAGE0.CHI, PAGE1.CHI, PAGE2.CHI, PAGE3.CHI, PAGE4.CHI
These are information files containing screens full of text which are presented to the user during the execution of CHIME as the program is prompting for various user inputs. These files may be printed for reference, if desired. They are also shown in Appendix A.

OEM08.FON and ROMAN.FON
These are the font files that are required by the orbit plotting routine.

# 9. REFERENCES

Cameron, A.G.W., in: *Essays in Nuclear Astrophysics*, ed. Barnes, Clayton, and Schramm, University of Cambridge Press, Cambridge, pp. 23-43, 1982.

Chen, J., D. Chenette, R. Clark, M. Garcia-Muñoz, T.G. Guzik, K. Pyle, Y. Sang, and J. Wefel, A model of galactic cosmic rays for use in calculating linear energy transfer spectra, *Adv. Sp. Res., 14*, No. 10, pp. 765-769, 1994.

Chen, J., D. Chenette, G. Guzik, M. Garcia-Muñoz, K. Pyle, Y. Sang, and J. Wefel, A model of solar energetic particles for use in calculating LET spectra developed from ONR-604 data, *Adv. Sp. Res., 14*, No. 10, pp. 675-680, 1994.

Chenette, D.L., T.G. Guzik, and J.P. Wefel, The LET spectrum and its uncertainty during the CRRES mission, *Adv. Sp. Res., 14*, No. 10, pp. 809-813, 1994a.

Chenette, D.L., J. Chen, E. Clayton, T.G. Guzik, J.P. Wefel, M. Garcia-Muñoz, C. Lopate, K.R. Pyle, K.P. Ray, E.G. Mullen, and D.A. Hardy, The CRRES/SPACERAD Heavy Ion Model of the Environment (CHIME) for Cosmic Ray and Solar Particle Effects on Electronic and Biological Systems in Space, *IEEE Trans. Nuc. Sci., NS-41*, p. 2332, 1994b.

Feynman, J., G. Spitale, J. Wang, and S. Gabriel, Interplanetary Proton Fluence Model: JPL 1991, *J. Geophys Res., 98*, 13281, 1993.

Garcia-Muñoz, M., K.R. Pyle, and J.A. Simpson, The 1973-1984 solar modulation of cosmic ray nuclei, *Proc. 19th Intl. Cosmic Ray Conf.* (LaJolla), *4*, pp. 409-412, 1985.

Pickel, James C., and James T. Blandford, Jr., Cosmic-ray-induced errors in MOS devices, *IEEE Trans. Nuc. Sci., NS-27*, p. 1006, 1980.

Reames, Donald V., Coronal element abundances derived from solar energetic particles, *Adv. Sp. Res.*, (in press), 1994.

Shoga, M., P. Adams, D.L. Chenette, R. Koga, and E.C. Smith, Verification of single event upset rate estimation methods with on-orbit observations, *IEEE Trans. Nuc. Sci, NS-34,* No. 6, pp. 1256-1261, 1987.

Wefel, J.P., An overview of cosmic ray research: Composition, acceleration, and propagation, in *Genesis and Propagation of Cosmic Rays*, M.M. Shapiro and J.P. Wefel, eds., pp. 1-40, D. Reidel Pub. Co., 1988.

Wilson, John W., Lawrence W. Townsend, Walter Schimmerling, Govind S. Khandelwal, Ferdous Khan, John E. Nealy, Francis A. Cucinotta, Lisa C. Simonsen, Judy L. Shinn, and John W. Norbury, *Transport Methods and Interactions for Space Radiations*, NASA Ref. Pub. 1257, p. 475, 1991.

## Appendix A          CHIME Information Page Screens

When CHIME is executed on a PC-compatible system, several screens of information are presented to the user to guide to help explain the operation of the program. These screens are presented here for information and reference.

### PAGE0.CHI

```
        CRRES/SPACERAD Heavy Ion Model of the Environment (CHIME) for
    Cosmic Ray and Solar Particle Effects on Electronic and Biological Systems

CHIME calculates models of the high energy heavy ion environment in space
and can provide estimates of the rate of single-particle radiation effects
in micro-electronic devices due to cosmic ray and solar-flare ions.

This software package includes several modules linked together:
First, CHIME will calculate a model for the fluxes of cosmic ray and solar
    energetic ions near earth for a time period or solar modulation level.
Second, these fluxes are modified to account for the effects of shielding
    by earth and its magnetic field based on a specified location or orbit.
Third, a linear energy transfer (LET) spectrum is calculated from the
    fluxes of step 2 and a shielded-target model for the sensitive region.
Finally, a single event upset rate can be calculated from the LET spectrum.

For more information see: IEEE Trans. Nuc. Sci., Vol. 41, p. 2332, 1994.
```

### PAGE1.CHI

```
In addition to the cosmic ray component of the heavy ion flux near earth,
CHIME supports a variety of solar flare energetic ion models. These models
are specified in the following sections.

Two sets of the solar energetic particle flux models are based on the
largest events observed during the CRRES mission. Those are the events
of 23 March 1991 and 4 June 1991. For each of these two events you may
select to include either the instantaneous peak flux for the event or
the average flux corresponding to the most intense 24-hour period. The
23 March event was iron-rich, but had a soft energy spectrum. The June
event had more normal composition and more flux at higher energies.

CHIME also supports the mission fluence model JPL-1991 (Feynman, et al.
1993). JPL-1991 yields total solar-particle-event fluence spectra based
on user-specified mission start and end times and probability level. The
model has 7 active years and 4 quiet years in each 11-year solar cycle.
```

## PAGE2.CHI

The cosmic ray, anomalous component, and solar energetic heavy ion fluxes
can be shielded or attenuated by the solid earth and by earth's magnetic
field. CHIME provides a method to estimate these effects based on the
geometric solid-angle of allowed arrival directions for charged particles
influenced by earth's magnetic field. The magnetic field is modeled as an
offset, tilted dipole for this calculation. The effects of this shielding
are negligible at distances of 100,000 km or more from the earth.

To take advantage of this calculation you must specify either an orbit or
a location near earth. In the next section you will be asked to specify
either a set of orbital elements or an earth-fixed location. CHIME will
calculate either the orbit-average geomagnetic shielding effect over the
specified time period, or will calculate the shielding at the requested
location. The coordinate system is earth-fixed, with Z along the earth's
rotation axis and X from the earth's center towards the prime meridian
at the equator. Perigee and apogee are altitudes measured from the surface.

## PAGE3.CHI

To estimate the effects of the heavy ions on a specific device or region
of interest, the energy spectra of all ions are integrated and organized
as a function of the energy deposited along a line as it penetrates the
region (linear energy transfer, LET). This particle flux LET spectrum is
used in subsequent calculations of single event upset rates. CHIME provides
the integral form of this spectrum, the total flux of ions incident on the
target with LET greater than or equal to the ordinate threshold value.

In CHIME a simple shielded-target geometry is used to calculate the LET
spectrum. You will specify the thickness of the shield as well as the
thickness of the target of interest behind this shield. Geometrically, the
shield is modeled as a large spherical shell with the target at its center.

Finally, while CHIME includes spectra for elements from hydrogen (Z=1)
through uranium (Z=92), for many purposes including only elements through
the iron group (to zinc at Z=30) will be sufficient (and 3 times faster).

## PAGE4.CHI

All of the input parameters are specified, and the calculation is underway.

First, CHIME will determine the interplanetary ion model by combining the
   cosmic ray and solar energetic ion components. The cosmic ray component
   will be integrated over time if a time period was specified.
Next, CHIME will integrate over all ion species (atomic number, Z) and
   their energy ranges as appropriate to accumulate the LET spectrum from
   the interplanetary environment model unshielded by earth and its field.
Thirdly, the orbit and geomagnetic shielding effect will be calculated.
Finally, CHIME will calculate another LET spectrum for the orbit-average
   heavy ion environment model shielded by the earth and its magnetic field.

Three sets of files from validation runs of CHIME are provided on the distribution disk. These files are all in the subdirectory named VALIDATE. The three sets of files correspond to three different sets of conditions as defined below. For reference, sections of each of the validation files for the solar minimum set are printed in this appendix.

The three sets of files provided with CHIME distribution version 3.5 are:

```
        For solar minimum conditions:    Files named SOLARMIN.*
        SOLARMIN  CHM              305 01-20-97     9:05a
        SOLARMIN  SPC          55,727 01-20-97      9:12a
        SOLARMIN  ORB          64,890 01-20-97      9:12a
        SOLARMIN  LET           3,652 01-20-97      9:12a
        SOLARMIN  SEU          24,938 01-20-97      3:21p


        For solar maximum conditions:   Files named SOLARMAX.*
        SOLARMAX  CHM              308 01-20-97     4:52p
        SOLARMAX  SPC          55,774 01-20-97      4:56p
        SOLARMAX  ORB         128,830 01-20-97      4:56p
        SOLARMAX  LET           3,667 01-20-97      4:56p
        SOLARMAX  SEU           5,112 01-20-97      4:57p


        To test the JPL 1991 solar model:  Files named CYCFLUNC.*
        CYCFLUNC  CHM              306 01-26-97     1:42p
        CYCFLUNC  SPC          53,306 01-26-97      1:52p
        CYCFLUNC  ORB              539 01-26-97     1:52p
        CYCFLUNC  LET           3,515 01-26-97      1:52p
        CYCFLUNC  SEU          30,578 02-10-97     12:05p
```

The input parameter (<model>.CHM) files are listed on the next page.

Sections of the SOLARMIN.* files are provided in the following pages of this appendix.

File: SOLARMIN.CHM     Input parameter file for solar minimum validation run.


```
SOLARMIN
Mon Jan 20 09:05:22 1997
Solar minimum conditions, phi = 400 MV, no solar particle fluxes
Typical space station/MIR orbit: 430 km altitude, 51 deg inclination
M
1994 1 1994 2
400 0 1 265
   430.00    430.00      0.00    51.00     0.00      0.0      0.0 86400.0    100.0
1000.000 10.000 1 3 Y
```


File: SOLARMAX.CHM     Input parameter file for solar maximum validation run.


```
SOLARMAX
Mon Jan 20 16:52:27 1997
Model for year 2003 (solar maximum) including peak flux of March '91
Eccentric polar orbit 300 x 1000 km altitude, 98 degree inclination
P
2003 1 2003 365
400 1 1 265
   300.00   1000.00    -85.00    98.00     0.00      0.0      0.0 172800.0    100.0
 200.000   1.000 2 3 N
```


File: CYCFLUNC.CHM     Input parameter file for solar cycle and JPL1991 validation runs.


```
CYCFLUNC
Sun Jan 26 13:42:59 1997
Solar cycle total fluence with JPL 10% model solar contribution
Single location at geosynchronous altitude over the USA
P
1987 1 1998 1
400 9 3 265
    -2.00 35800.00      0.00   -90.00     0.00      0.0      0.0 172800.0    100.0
 100.000   1.000 1 3 Y
```


43

File: SOLARMIN.SPC    Ion flux spectrum listing file for solar minimum validation run.


Heavy Ion Energy Spectrum Output File from CHIME V3.5

Model file name: SOLARMIN.CHM       Dated: Mon Jan 20 09:05:22 1997
Solar minimum conditions, phi = 400 MV, no solar particle fluxes
Typical space station/MIR orbit: 430 km altitude, 51 deg inclination

Galactic cosmic ray spectrum for level of solar modulation phi = 400 MV

No solar flare heavy ion enhancement included.

Free-space spectrum.  No geomagnetic shielding.

Galactic Cosmic Ray Flux
Units:  particles/(m2 s sr MeV/nucleon)

| Energy Z= | 1.00 | 2.00 | 3.00 | 4.00 | 5.00 | 6.00 | 7.00 | 8.00 |
|---|---|---|---|---|---|---|---|---|
| (MeV/n) M= | 1.00 | 4.00 | 6.45 | 8.10 | 10.70 | 12.03 | 14.42 | 16.03 |
| 10.0 | 2.20e-01 | 5.84e-02 | 1.18e-04 | 5.43e-05 | 2.20e-04 | 9.94e-04 | 1.97e-04 | 9.36e-04 |
| 11.2 | 2.45e-01 | 6.50e-02 | 1.31e-04 | 6.06e-05 | 2.45e-04 | 1.11e-03 | 2.20e-04 | 1.04e-03 |
| 12.6 | 2.76e-01 | 7.30e-02 | 1.47e-04 | 6.81e-05 | 2.75e-04 | 1.24e-03 | 2.47e-04 | 1.17e-03 |
| 14.1 | 3.10e-01 | 8.21e-02 | 1.66e-04 | 7.68e-05 | 3.10e-04 | 1.40e-03 | 2.79e-04 | 1.32e-03 |
| 15.8 | 3.48e-01 | 9.19e-02 | 1.86e-04 | 8.61e-05 | 3.48e-04 | 1.57e-03 | 3.13e-04 | 1.48e-03 |
| 17.8 | 3.89e-01 | 1.02e-01 | 2.08e-04 | 9.62e-05 | 3.88e-04 | 1.75e-03 | 3.49e-04 | 1.65e-03 |
| 19.9 | 4.34e-01 | 1.14e-01 | 2.32e-04 | 1.07e-04 | 4.33e-04 | 1.95e-03 | 3.90e-04 | 1.84e-03 |
| 22.4 | 4.85e-01 | 1.27e-01 | 2.59e-04 | 1.20e-04 | 4.83e-04 | 2.18e-03 | 4.35e-04 | 2.05e-03 |
| 25.1 | 5.42e-01 | 1.41e-01 | 2.90e-04 | 1.34e-04 | 5.40e-04 | 2.43e-03 | 4.87e-04 | 2.29e-03 |
| 28.2 | 6.05e-01 | 1.56e-01 | 3.23e-04 | 1.50e-04 | 6.02e-04 | 2.70e-03 | 5.42e-04 | 2.55e-03 |
| 31.6 | 6.75e-01 | 1.73e-01 | 3.60e-04 | 1.67e-04 | 6.69e-04 | 2.99e-03 | 6.03e-04 | 2.83e-03 |
| 35.4 | 7.52e-01 | 1.91e-01 | 4.00e-04 | 1.86e-04 | 7.43e-04 | 3.31e-03 | 6.70e-04 | 3.13e-03 |
| 39.7 | 8.37e-01 | 2.09e-01 | 4.44e-04 | 2.06e-04 | 8.23e-04 | 3.65e-03 | 7.42e-04 | 3.46e-03 |
| 44.6 | 9.31e-01 | 2.29e-01 | 4.92e-04 | 2.28e-04 | 9.10e-04 | 4.02e-03 | 8.21e-04 | 3.81e-03 |
| 50.0 | 1.03e+00 | 2.50e-01 | 5.43e-04 | 2.53e-04 | 1.00e-03 | 4.41e-03 | 9.06e-04 | 4.18e-03 |

(many lines deleted here.  See distribution disk for complete file.)

| 9923.3 | 1.91e-02 | 1.46e-03 | 5.19e-06 | 2.86e-06 | 6.82e-06 | 3.48e-05 | 7.34e-06 | 3.75e-05 |
|---|---|---|---|---|---|---|---|---|
| 11132.7 | 1.41e-02 | 1.08e-03 | 3.69e-06 | 2.05e-06 | 4.87e-06 | 2.59e-05 | 5.32e-06 | 2.81e-05 |
| 12489.5 | 1.04e-02 | 7.99e-04 | 2.61e-06 | 1.46e-06 | 3.45e-06 | 1.92e-05 | 3.84e-06 | 2.09e-05 |
| 14011.6 | 7.66e-03 | 5.88e-04 | 1.84e-06 | 1.03e-06 | 2.44e-06 | 1.42e-05 | 2.76e-06 | 1.55e-05 |
| 15719.3 | 5.60e-03 | 4.31e-04 | 1.28e-06 | 7.25e-07 | 1.71e-06 | 1.04e-05 | 1.97e-06 | 1.15e-05 |
| 17635.1 | 4.09e-03 | 3.15e-04 | 8.94e-07 | 5.09e-07 | 1.20e-06 | 7.64e-06 | 1.40e-06 | 8.47e-06 |
| 19784.3 | 2.98e-03 | 2.30e-04 | 6.20e-07 | 3.54e-07 | 8.34e-07 | 5.58e-06 | 9.94e-07 | 6.22e-06 |
| 22195.5 | 2.16e-03 | 1.67e-04 | 4.28e-07 | 2.46e-07 | 5.78e-07 | 4.06e-06 | 7.02e-07 | 4.55e-06 |
| 24900.6 | 1.56e-03 | 1.21e-04 | 2.95e-07 | 1.70e-07 | 4.01e-07 | 2.96e-06 | 4.96e-07 | 3.33e-06 |
| 27935.3 | 1.13e-03 | 8.78e-05 | 2.03e-07 | 1.18e-07 | 2.77e-07 | 2.15e-06 | 3.49e-07 | 2.43e-06 |
| 31339.9 | 8.18e-04 | 6.37e-05 | 1.40e-07 | 8.12e-08 | 1.91e-07 | 1.56e-06 | 2.46e-07 | 1.78e-06 |
| 35159.5 | 5.92e-04 | 4.62e-05 | 9.63e-08 | 5.62e-08 | 1.32e-07 | 1.14e-06 | 1.73e-07 | 1.30e-06 |
| 39444.5 | 4.29e-04 | 3.35e-05 | 6.63e-08 | 3.88e-08 | 9.15e-08 | 8.26e-07 | 1.22e-07 | 9.49e-07 |
| 44251.8 | 3.12e-04 | 2.45e-05 | 4.60e-08 | 2.71e-08 | 6.38e-08 | 6.05e-07 | 8.67e-08 | 6.99e-07 |
| 49645.0 | 2.27e-04 | 1.78e-05 | 3.18e-08 | 1.88e-08 | 4.43e-08 | 4.41e-07 | 6.13e-08 | 5.12e-07 |

| Energy | Z= 9.00 | 10.00 | 11.00 | 12.00 | 13.00 | 14.00 | 15.00 | 16.00 |
|---|---|---|---|---|---|---|---|---|
| (MeV/n) | M= 19.00 | 20.66 | 23.00 | 24.36 | 26.87 | 28.18 | 31.00 | 32.35 |
| 10.0 | 1.31e-05 | 1.36e-04 | 2.04e-05 | 1.70e-04 | 2.09e-05 | 1.21e-04 | 2.91e-06 | 1.69e-05 |
| 11.2 | 1.46e-05 | 1.52e-04 | 2.27e-05 | 1.89e-04 | 2.33e-05 | 1.34e-04 | 3.25e-06 | 1.89e-05 |
| 12.6 | 1.64e-05 | 1.71e-04 | 2.55e-05 | 2.13e-04 | 2.62e-05 | 1.51e-04 | 3.65e-06 | 2.13e-05 |
| 14.1 | 1.85e-05 | 1.92e-04 | 2.88e-05 | 2.39e-04 | 2.95e-05 | 1.70e-04 | 4.12e-06 | 2.39e-05 |
| 15.8 | 2.07e-05 | 2.15e-04 | 3.22e-05 | 2.68e-04 | 3.31e-05 | 1.91e-04 | 4.62e-06 | 2.69e-05 |
| 17.8 | 2.32e-05 | 2.40e-04 | 3.60e-05 | 3.00e-04 | 3.69e-05 | 2.13e-04 | 5.17e-06 | 3.00e-05 |
| 19.9 | 2.59e-05 | 2.68e-04 | 4.02e-05 | 3.34e-04 | 4.12e-05 | 2.38e-04 | 5.78e-06 | 3.35e-05 |
| 22.4 | 2.89e-05 | 2.99e-04 | 4.49e-05 | 3.73e-04 | 4.60e-05 | 2.65e-04 | 6.47e-06 | 3.75e-05 |
| 25.1 | 3.24e-05 | 3.34e-04 | 5.02e-05 | 4.17e-04 | 5.14e-05 | 2.97e-04 | 7.25e-06 | 4.19e-05 |
| 28.2 | 3.61e-05 | 3.72e-04 | 5.59e-05 | 4.64e-04 | 5.73e-05 | 3.30e-04 | 8.10e-06 | 4.68e-05 |
| 31.6 | 4.02e-05 | 4.13e-04 | 6.22e-05 | 5.16e-04 | 6.38e-05 | 3.67e-04 | 9.04e-06 | 5.21e-05 |
| 35.4 | 4.48e-05 | 4.58e-04 | 6.91e-05 | 5.72e-04 | 7.08e-05 | 4.07e-04 | 1.01e-05 | 5.79e-05 |
| 39.7 | 4.97e-05 | 5.06e-04 | 7.65e-05 | 6.33e-04 | 7.84e-05 | 4.51e-04 | 1.12e-05 | 6.43e-05 |
| 44.6 | 5.51e-05 | 5.58e-04 | 8.46e-05 | 6.98e-04 | 8.67e-05 | 4.98e-04 | 1.25e-05 | 7.12e-05 |
| 50.0 | 6.09e-05 | 6.14e-04 | 9.33e-05 | 7.68e-04 | 9.56e-05 | 5.48e-04 | 1.39e-05 | 7.87e-05 |
| 56.1 | 6.71e-05 | 6.72e-04 | 1.03e-04 | 8.41e-04 | 1.05e-04 | 6.01e-04 | 1.53e-05 | 8.67e-05 |
| 63.0 | 7.38e-05 | 7.34e-04 | 1.12e-04 | 9.18e-04 | 1.15e-04 | 6.56e-04 | 1.70e-05 | 9.52e-05 |
| 70.6 | 8.07e-05 | 7.96e-04 | 1.22e-04 | 9.96e-04 | 1.25e-04 | 7.13e-04 | 1.87e-05 | 1.04e-04 |
| 79.2 | 8.81e-05 | 8.60e-04 | 1.33e-04 | 1.08e-03 | 1.36e-04 | 7.71e-04 | 2.05e-05 | 1.13e-04 |
| 88.9 | 9.57e-05 | 9.23e-04 | 1.44e-04 | 1.16e-03 | 1.47e-04 | 8.30e-04 | 2.25e-05 | 1.23e-04 |
| 99.7 | 1.03e-04 | 9.85e-04 | 1.54e-04 | 1.23e-03 | 1.58e-04 | 8.87e-04 | 2.45e-05 | 1.33e-04 |
| 111.9 | 1.11e-04 | 1.04e-03 | 1.65e-04 | 1.31e-03 | 1.69e-04 | 9.42e-04 | 2.66e-05 | 1.42e-04 |

(many lines deleted here.  See distribution disk for complete file.)

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| 3142.0 | 1.14e-05 | 8.45e-05 | 1.53e-05 | 1.07e-04 | 1.72e-05 | 8.38e-05 | 3.97e-06 | 1.72e-05 |
| 3525.0 | 8.85e-06 | 6.64e-05 | 1.19e-05 | 8.47e-05 | 1.36e-05 | 6.65e-05 | 3.06e-06 | 1.34e-05 |
| 3954.6 | 6.80e-06 | 5.19e-05 | 9.24e-06 | 6.66e-05 | 1.07e-05 | 5.25e-05 | 2.36e-06 | 1.04e-05 |
| 4436.6 | 5.18e-06 | 4.02e-05 | 7.09e-06 | 5.20e-05 | 8.30e-06 | 4.12e-05 | 1.81e-06 | 8.08e-06 |
| 4977.3 | 3.92e-06 | 3.10e-05 | 5.41e-06 | 4.03e-05 | 6.43e-06 | 3.21e-05 | 1.38e-06 | 6.23e-06 |
| 5583.9 | 2.94e-06 | 2.37e-05 | 4.10e-06 | 3.11e-05 | 4.94e-06 | 2.49e-05 | 1.04e-06 | 4.78e-06 |
| 6264.4 | 2.18e-06 | 1.80e-05 | 3.08e-06 | 2.38e-05 | 3.77e-06 | 1.91e-05 | 7.84e-07 | 3.64e-06 |
| 7027.9 | 1.61e-06 | 1.37e-05 | 2.31e-06 | 1.82e-05 | 2.86e-06 | 1.47e-05 | 5.88e-07 | 2.77e-06 |
| 7884.4 | 1.19e-06 | 1.03e-05 | 1.72e-06 | 1.38e-05 | 2.16e-06 | 1.12e-05 | 4.37e-07 | 2.09e-06 |
| 8845.3 | 8.66e-07 | 7.71e-06 | 1.27e-06 | 1.04e-05 | 1.62e-06 | 8.48e-06 | 3.23e-07 | 1.57e-06 |
| 9923.3 | 6.29e-07 | 5.75e-06 | 9.34e-07 | 7.84e-06 | 1.21e-06 | 6.41e-06 | 2.38e-07 | 1.17e-06 |
| 11132.7 | 4.53e-07 | 4.27e-06 | 6.83e-07 | 5.86e-06 | 8.99e-07 | 4.82e-06 | 1.74e-07 | 8.71e-07 |
| 12489.5 | 3.25e-07 | 3.16e-06 | 4.98e-07 | 4.37e-06 | 6.64e-07 | 3.61e-06 | 1.26e-07 | 6.45e-07 |
| 14011.6 | 2.32e-07 | 2.33e-06 | 3.61e-07 | 3.25e-06 | 4.89e-07 | 2.69e-06 | 9.15e-08 | 4.76e-07 |
| 15719.3 | 1.64e-07 | 1.70e-06 | 2.60e-07 | 2.40e-06 | 3.57e-07 | 2.00e-06 | 6.58e-08 | 3.49e-07 |
| 17635.1 | 1.16e-07 | 1.25e-06 | 1.87e-07 | 1.77e-06 | 2.60e-07 | 1.48e-06 | 4.72e-08 | 2.56e-07 |
| 19784.3 | 8.15e-08 | 9.08e-07 | 1.34e-07 | 1.30e-06 | 1.89e-07 | 1.09e-06 | 3.37e-08 | 1.86e-07 |
| 22195.5 | 5.70e-08 | 6.59e-07 | 9.51e-08 | 9.53e-07 | 1.36e-07 | 8.03e-07 | 2.39e-08 | 1.35e-07 |
| 24900.6 | 3.98e-08 | 4.79e-07 | 6.78e-08 | 6.98e-07 | 9.83e-08 | 5.90e-07 | 1.70e-08 | 9.82e-08 |
| 27935.3 | 2.77e-08 | 3.47e-07 | 4.81e-08 | 5.10e-07 | 7.07e-08 | 4.33e-07 | 1.20e-08 | 7.12e-08 |
| 31339.9 | 1.93e-08 | 2.51e-07 | 3.42e-08 | 3.73e-07 | 5.09e-08 | 3.17e-07 | 8.53e-09 | 5.16e-08 |
| 35159.5 | 1.34e-08 | 1.82e-07 | 2.43e-08 | 2.72e-07 | 3.66e-08 | 2.33e-07 | 6.05e-09 | 3.74e-08 |
| 39444.5 | 9.36e-09 | 1.32e-07 | 1.73e-08 | 1.99e-07 | 2.64e-08 | 1.71e-07 | 4.29e-09 | 2.71e-08 |
| 44251.8 | 6.58e-09 | 9.64e-08 | 1.24e-08 | 1.47e-07 | 1.92e-08 | 1.26e-07 | 3.06e-09 | 1.98e-08 |
| 49645.0 | 4.60e-09 | 7.01e-08 | 8.83e-09 | 1.08e-07 | 1.38e-08 | 9.29e-08 | 2.18e-09 | 1.44e-08 |

| Energy | Z= 17.00 | 18.00 | 19.00 | 20.00 | 21.00 | 22.00 | 23.00 | 24.00 |
|---|---|---|---|---|---|---|---|---|
| (MeV/n) | M= 35.79 | 37.22 | 39.91 | 41.60 | 45.00 | 47.19 | 50.35 | 52 08 |
| 10.0 | 2.04e-06 | 5.80e-06 | 3.65e-06 | 1.13e-05 | 2.76e-06 | 1.25e-05 | 6.86e-06 | 1.56e-05 |
| 11.2 | 2.28e-06 | 6.47e-06 | 4.07e-06 | 1.26e-05 | 3.08e-06 | 1.40e-05 | 7.64e-06 | 1.73e-05 |
| 12.6 | 2.56e-06 | 7.28e-06 | 4.58e-06 | 1.42e-05 | 3.46e-06 | 1.57e-05 | 8.58e-06 | 1.95e-05 |
| 14.1 | 2.89e-06 | 8.20e-06 | 5.16e-06 | 1.60e-05 | 3.90e-06 | 1.77e-05 | 9.66e-06 | 2.19e-05 |
| 15.8 | 3.25e-06 | 9.21e-06 | 5.79e-06 | 1.79e-05 | 4.37e-06 | 1.98e-05 | 1.08e-05 | 2.46e-05 |
| 17.8 | 3.63e-06 | 1.03e-05 | 6.48e-06 | 2.01e-05 | 4.89e-06 | 2.21e-05 | 1.21e-05 | 2.74e-05 |
| 19.9 | 4.06e-06 | 1.15e-05 | 7.25e-06 | 2.24e-05 | 5.46e-06 | 2.47e-05 | 1.34e-05 | 3.06e-05 |
| 22.4 | 4.55e-06 | 1.29e-05 | 8.12e-06 | 2.50e-05 | 6.10e-06 | 2.76e-05 | 1.50e-05 | 3.41e-05 |
| 25.1 | 5.11e-06 | 1.44e-05 | 9.10e-06 | 2.80e-05 | 6.83e-06 | 3.08e-05 | 1.67e-05 | 3.81e-05 |
| 28.2 | 5.71e-06 | 1.61e-05 | 1.02e-05 | 3.13e-05 | 7.62e-06 | 3.43e-05 | 1.86e-05 | 4.23e-05 |
| 31.6 | 6.39e-06 | 1.80e-05 | 1.14e-05 | 3.48e-05 | 8.49e-06 | 3.81e-05 | 2.06e-05 | 4.70e-05 |
| 35.4 | 7.13e-06 | 2.01e-05 | 1.27e-05 | 3.88e-05 | 9.44e-06 | 4.23e-05 | 2.29e-05 | 5.21e-05 |
| 39.7 | 7.96e-06 | 2.23e-05 | 1.42e-05 | 4.30e-05 | 1.05e-05 | 4.68e-05 | 2.52e-05 | 5.75e-05 |
| 44.6 | 8.88e-06 | 2.48e-05 | 1.58e-05 | 4.77e-05 | 1.16e-05 | 5.17e-05 | 2.78e-05 | 6.34e-05 |
| 50.0 | 9.88e-06 | 2.76e-05 | 1.75e-05 | 5.28e-05 | 1.29e-05 | 5.69e-05 | 3.05e-05 | 6.96e-05 |
| 56.1 | 1.10e-05 | 3.05e-05 | 1.95e-05 | 5.82e-05 | 1.42e-05 | 6.25e-05 | 3.34e-05 | 7.61e-05 |
| 63.0 | 1.22e-05 | 3.37e-05 | 2.16e-05 | 6.41e-05 | 1.56e-05 | 6.84e-05 | 3.64e-05 | 8.30e-05 |
| 70.6 | 1.35e-05 | 3.71e-05 | 2.39e-05 | 7.02e-05 | 1.71e-05 | 7.45e-05 | 3.94e-05 | 8.99e-05 |
| 79.2 | 1.49e-05 | 4.07e-05 | 2.64e-05 | 7.68e-05 | 1.87e-05 | 8.10e-05 | 4.26e-05 | 9.71e-05 |
| 88.9 | 1.65e-05 | 4.46e-05 | 2.90e-05 | 8.36e-05 | 2.05e-05 | 8.76e-05 | 4.58e-05 | 1.04e-04 |
| 99.7 | 1.81e-05 | 4.87e-05 | 3.19e-05 | 9.06e-05 | 2.22e-05 | 9.43e-05 | 4.90e-05 | 1.11e-04 |
| 111.9 | 1.99e-05 | 5.29e-05 | 3.50e-05 | 9.79e-05 | 2.41e-05 | 1.01e-04 | 5.22e-05 | 1.18e-04 |

(many lines deleted here.  See distribution disk for complete file.)

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| 3142.0 | 3.79e-06 | 7.34e-06 | 5.33e-06 | 1.09e-05 | 2.34e-06 | 8.07e-06 | 3.20e-06 | 7.22e-06 |
| 3525.0 | 2.90e-06 | 5.61e-06 | 4.06e-06 | 8.42e-06 | 1.76e-06 | 6.24e-06 | 2.50e-06 | 5.71e-06 |
| 3954.6 | 2.23e-06 | 4.28e-06 | 3.10e-06 | 6.51e-06 | 1.32e-06 | 4.80e-06 | 1.94e-06 | 4.47e-06 |
| 4436.6 | 1.71e-06 | 3.26e-06 | 2.36e-06 | 5.02e-06 | 9.83e-07 | 3.66e-06 | 1.49e-06 | 3.47e-06 |
| 4977.3 | 1.30e-06 | 2.47e-06 | 1.79e-06 | 3.85e-06 | 7.37e-07 | 2.79e-06 | 1.14e-06 | 2.67e-06 |
| 5583.9 | 9.95e-07 | 1.87e-06 | 1.35e-06 | 2.95e-06 | 5.56e-07 | 2.13e-06 | 8.71e-07 | 2.05e-06 |
| 6264.4 | 7.54e-07 | 1.40e-06 | 1.02e-06 | 2.24e-06 | 4.19e-07 | 1.61e-06 | 6.60e-07 | 1.56e-06 |
| 7027.9 | 5.70e-07 | 1.05e-06 | 7.64e-07 | 1.70e-06 | 3.15e-07 | 1.21e-06 | 4.98e-07 | 1.18e-06 |
| 7884.4 | 4.28e-07 | 7.81e-07 | 5.69e-07 | 1.28e-06 | 2.36e-07 | 9.08e-07 | 3.73e-07 | 8.88e-07 |
| 8845.3 | 3.19e-07 | 5.77e-07 | 4.21e-07 | 9.61e-07 | 1.75e-07 | 6.76e-07 | 2.78e-07 | 6.64e-07 |
| 9923.3 | 2.37e-07 | 4.24e-07 | 3.10e-07 | 7.17e-07 | 1.29e-07 | 5.01e-07 | 2.06e-07 | 4.95e-07 |
| 11132.7 | 1.74e-07 | 3.10e-07 | 2.27e-07 | 5.32e-07 | 9.46e-08 | 3.68e-07 | 1.52e-07 | 3.66e-07 |
| 12489.5 | 1.28e-07 | 2.25e-07 | 1.65e-07 | 3.92e-07 | 6.90e-08 | 2.69e-07 | 1.11e-07 | 2.69e-07 |
| 14011.6 | 9.30e-08 | 1.63e-07 | 1.19e-07 | 2.88e-07 | 5.00e-08 | 1.96e-07 | 8.09e-08 | 1.97e-07 |
| 15719.3 | 6.72e-08 | 1.17e-07 | 8.54e-08 | 2.10e-07 | 3.60e-08 | 1.42e-07 | 5.85e-08 | 1.43e-07 |
| 17635.1 | 4.84e-08 | 8.40e-08 | 6.11e-08 | 1.53e-07 | 2.58e-08 | 1.02e-07 | 4.22e-08 | 1.04e-07 |
| 19784.3 | 3.45e-08 | 5.99e-08 | 4.34e-08 | 1.11e-07 | 1.84e-08 | 7.29e-08 | 3.02e-08 | 7.50e-08 |
| 22195.5 | 2.45e-08 | 4.26e-08 | 3.07e-08 | 8.02e-08 | 1.31e-08 | 5.19e-08 | 2.15e-08 | 5.38e-08 |
| 24900.6 | 1.74e-08 | 3.03e-08 | 2.17e-08 | 5.79e-08 | 9.25e-09 | 3.69e-08 | 1.53e-08 | 3.85e-08 |
| 27935.3 | 1.23e-08 | 2.15e-08 | 1.52e-08 | 4.17e-08 | 6.53e-09 | 2.61e-08 | 1.09e-08 | 2.75e-08 |
| 31339.9 | 8.67e-09 | 1.53e-08 | 1.07e-08 | 3.00e-08 | 4.61e-09 | 1.85e-08 | 7.72e-09 | 1.97e-08 |
| 35159.5 | 6.13e-09 | 1.08e-08 | 7.56e-09 | 2.16e-08 | 3.26e-09 | 1.31e-08 | 5.49e-09 | 1.40e-08 |
| 39444.5 | 4.34e-09 | 7.69e-09 | 5.32e-09 | 1.56e-08 | 2.30e-09 | 9.33e-09 | 3.90e-09 | 1.00e-08 |
| 44251.8 | 3.09e-09 | 5.51e-09 | 3.78e-09 | 1.13e-08 | 1.64e-09 | 6.67e-09 | 2.79e-09 | 7.24e-09 |
| 49645.0 | 2.19e-09 | 3.92e-09 | 2.67e-09 | 8.17e-09 | 1.16e-09 | 4.75e-09 | 1.99e-09 | 5.19e-09 |

| Energy | Z= 25.00 | 26.00 | 27.00 | 28.00 |
|---|---|---|---|---|
| (MeV/n) | M= 53.83 | 55.88 | 58.23 | 58.77 |
| 10.0 | 8.30e-06 | 8.14e-05 | 2.97e-07 | 3.26e-06 |
| 11.2 | 9.25e-06 | 9.08e-05 | 3.31e-07 | 3.64e-06 |
| 12.6 | 1.04e-05 | 1.02e-04 | 3.72e-07 | 4.09e-06 |
| 14.1 | 1.17e-05 | 1.15e-04 | 4.20e-07 | 4.61e-06 |
| 15.8 | 1.31e-05 | 1.29e-04 | 4.71e-07 | 5.16e-06 |
| 17.8 | 1.46e-05 | 1.44e-04 | 5.27e-07 | 5.77e-06 |
| 19.9 | 1.63e-05 | 1.61e-04 | 5.88e-07 | 6.44e-06 |
| 22.4 | 1.82e-05 | 1.79e-04 | 6.59e-07 | 7.20e-06 |
| 25.1 | 2.04e-05 | 2.01e-04 | 7.38e-07 | 8.05e-06 |
| 28.2 | 2.27e-05 | 2.24e-04 | 8.24e-07 | 8.97e-06 |
| 31.6 | 2.52e-05 | 2.49e-04 | 9.20e-07 | 9.99e-06 |
| 35.4 | 2.79e-05 | 2.76e-04 | 1.03e-06 | 1.11e-05 |
| 39.7 | 3.09e-05 | 3.06e-04 | 1.14e-06 | 1.23e-05 |
| 44.6 | 3.41e-05 | 3.38e-04 | 1.27e-06 | 1.36e-05 |
| 50.0 | 3.75e-05 | 3.73e-04 | 1.40e-06 | 1.50e-05 |
| 56.1 | 4.11e-05 | 4.10e-04 | 1.55e-06 | 1.65e-05 |
| 63.0 | 4.49e-05 | 4.48e-04 | 1.71e-06 | 1.81e-05 |
| 70.6 | 4.88e-05 | 4.88e-04 | 1.88e-06 | 1.97e-05 |
| 79.2 | 5.28e-05 | 5.29e-04 | 2.06e-06 | 2.14e-05 |
| 88.9 | 5.69e-05 | 5.71e-04 | 2.25e-06 | 2.31e-05 |
| 99.7 | 6.08e-05 | 6.11e-04 | 2.44e-06 | 2.48e-05 |
| 111.9 | 6.47e-05 | 6.50e-04 | 2.63e-06 | 2.64e-05 |

(many lines deleted here.  See distribution disk for complete file.)

| | | | | |
|---|---|---|---|---|
| 3142.0 | 5.56e-06 | 6.01e-05 | 2.92e-07 | 2.62e-06 |
| 3525.0 | 4.42e-06 | 4.82e-05 | 2.33e-07 | 2.10e-06 |
| 3954.6 | 3.49e-06 | 3.84e-05 | 1.84e-07 | 1.68e-06 |
| 4436.6 | 2.73e-06 | 3.04e-05 | 1.45e-07 | 1.33e-06 |
| 4977.3 | 2.12e-06 | 2.39e-05 | 1.13e-07 | 1.05e-06 |
| 5583.9 | 1.64e-06 | 1.87e-05 | 8.75e-08 | 8.24e-07 |
| 6264.4 | 1.25e-06 | 1.45e-05 | 6.73e-08 | 6.41e-07 |
| 7027.9 | 9.55e-07 | 1.12e-05 | 5.16e-08 | 4.97e-07 |
| 7884.4 | 7.23e-07 | 8.64e-06 | 3.94e-08 | 3.84e-07 |
| 8845.3 | 5.44e-07 | 6.62e-06 | 2.98e-08 | 2.94e-07 |
| 9923.3 | 4.08e-07 | 5.06e-06 | 2.25e-08 | 2.25e-07 |
| 11132.7 | 3.03e-07 | 3.84e-06 | 1.69e-08 | 1.71e-07 |
| 12489.5 | 2.24e-07 | 2.90e-06 | 1.26e-08 | 1.30e-07 |
| 14011.6 | 1.65e-07 | 2.19e-06 | 9.41e-09 | 9.82e-08 |
| 15719.3 | 1.20e-07 | 1.64e-06 | 6.96e-09 | 7.37e-08 |
| 17635.1 | 8.77e-08 | 1.23e-06 | 5.13e-09 | 5.53e-08 |
| 19784.3 | 6.34e-08 | 9.15e-07 | 3.77e-09 | 4.13e-08 |
| 22195.5 | 4.56e-08 | 6.79e-07 | 2.76e-09 | 3.07e-08 |
| 24900.6 | 3.28e-08 | 5.04e-07 | 2.01e-09 | 2.28e-08 |
| 27935.3 | 2.34e-08 | 3.73e-07 | 1.47e-09 | 1.69e-08 |
| 31339.9 | 1.68e-08 | 2.76e-07 | 1.07e-09 | 1.25e-08 |
| 35159.5 | 1.20e-08 | 2.04e-07 | 7.80e-10 | 9.31e-09 |
| 39444.5 | 8.63e-09 | 1.51e-07 | 5.69e-10 | 6.91e-09 |
| 44251.8 | 6.23e-09 | 1.13e-07 | 4.18e-10 | 5.16e-09 |
| 49645.0 | 4.48e-09 | 8.39e-08 | 3.06e-10 | 3.84e-09 |

Anomalous Component Flux     Units:  particles/(m2 s sr MeV/nuc)

| AC E Z= | 1.00 | 1.00 | 1.00 | 1.00 |
|---|---|---|---|---|
| (MeV/n) M= | 4.00 | 14.00 | 16.00 | 20.00 |
| 10.0 | 1.47e+00 | 2.39e-02 | 1.81e-01 | 8.56e-03 |
| 10.7 | 1.48e+00 | 2.14e-02 | 1.59e-01 | 7.34e-03 |
| 11.5 | 1.49e+00 | 1.89e-02 | 1.39e-01 | 6.24e-03 |
| 12.4 | 1.50e+00 | 1.66e-02 | 1.20e-01 | 5.26e-03 |
| 13.3 | 1.48e+00 | 1.44e-02 | 1.03e-01 | 4.40e-03 |
| 14.3 | 1.46e+00 | 1.24e-02 | 8.73e-02 | 3.66e-03 |
| 15.4 | 1.42e+00 | 1.07e-02 | 7.37e-02 | 3.01e-03 |
| 16.5 | 1.38e+00 | 9.05e-03 | 6.17e-02 | 2.47e-03 |
| 17.8 | 1.32e+00 | 7.61e-03 | 5.12e-02 | 2.00e-03 |
| 19.1 | 1.25e+00 | 6.35e-03 | 4.22e-02 | 1.61e-03 |
| 20.5 | 1.18e+00 | 5.26e-03 | 3.45e-02 | 1.29e-03 |
| 22.0 | 1.09e+00 | 4.31e-03 | 2.79e-02 | 1.02e-03 |
| 23.7 | 1.00e+00 | 3.51e-03 | 2.25e-02 | 8.09e-04 |
| 25.5 | 9.12e-01 | 2.83e-03 | 1.79e-02 | 6.34e-04 |
| 27.4 | 8.18e-01 | 2.25e-03 | 1.41e-02 | 4.92e-04 |
| 29.4 | 7.24e-01 | 1.76e-03 | 1.10e-02 | 3.79e-04 |
| 31.6 | 6.32e-01 | 1.36e-03 | 8.46e-03 | 2.89e-04 |
| 33.9 | 5.44e-01 | 1.02e-03 | 6.36e-03 | 2.16e-04 |
| 36.5 | 4.61e-01 | 7.42e-04 | 4.62e-03 | 1.58e-04 |
| 39.2 | 3.85e-01 | 5.16e-04 | 3.23e-03 | 1.11e-04 |
| 42.1 | 3.16e-01 | 3.41e-04 | 2.13e-03 | 7.36e-05 |
| 45.2 | 2.56e-01 | 2.15e-04 | 1.34e-03 | 4.61e-05 |
| 48.6 | 2.04e-01 | 1.32e-04 | 8.16e-04 | 2.78e-05 |

(many lines deleted here.  See distribution disk for complete file.)

| 451.2 | 1.19e-06 | 2.37e-15 | 1.15e-14 | 2.74e-16 |
|---|---|---|---|---|
| 484.9 | 7.28e-07 | 9.71e-16 | 4.71e-15 | 1.11e-16 |
| 521.0 | 4.43e-07 | 3.97e-16 | 1.92e-15 | 4.51e-17 |
| 559.8 | 2.68e-07 | 1.62e-16 | 7.79e-16 | 1.82e-17 |
| 601.5 | 1.62e-07 | 6.57e-17 | 3.15e-16 | 7.30e-18 |
| 646.4 | 9.73e-08 | 2.66e-17 | 1.27e-16 | 2.93e-18 |
| 694.5 | 5.85e-08 | 1.09e-17 | 5.16e-17 | 1.19e-18 |
| 746.3 | 3.50e-08 | 4.40e-18 | 2.09e-17 | 4.78e-19 |
| 801.9 | 2.08e-08 | 1.78e-18 | 8.41e-18 | 1.91e-19 |
| 861.7 | 1.24e-08 | 7.13e-19 | 3.36e-18 | 7.62e-20 |
| 925.9 | 7.33e-09 | 2.88e-19 | 1.36e-18 | 3.06e-20 |
| 994.9 | 4.33e-09 | 1.16e-19 | 5.46e-19 | 1.23e-20 |
| 1069.0 | 2.55e-09 | 4.69e-20 | 2.19e-19 | 4.92e-21 |
| 1148.7 | 1.49e-09 | 1.88e-20 | 8.76e-20 | 1.96e-21 |
| 1234.3 | 8.77e-10 | 7.53e-21 | 3.50e-20 | 7.82e-22 |
| 1326.3 | 5.14e-10 | 3.01e-21 | 1.40e-20 | 3.10e-22 |
| 1425.1 | 3.00e-10 | 1.20e-21 | 5.58e-21 | 1.23e-22 |
| 1531.3 | 1.74e-10 | 4.79e-22 | 2.22e-21 | 4.90e-23 |
| 1645.4 | 1.01e-10 | 1.91e-22 | 8.81e-22 | 1.94e-23 |
| 1768.0 | 5.89e-11 | 7.62e-23 | 3.51e-22 | 7.72e-24 |
| 1899.8 | 3.43e-11 | 3.05e-23 | 1.41e-22 | 3.08e-24 |
| 2041.4 | 1.99e-11 | 1.22e-23 | 5.63e-23 | 1.23e-24 |

```
Specification for orbit and geomagnetic shielding calculation:
     Perigee altitude in kilometers = 430
     Apogee altitude in kilometers = 430
     Perigee angle in degrees, Beta = 0.00
     Inclination angle in degrees = 51.00
     Longitude of ascending node in degrees = 0.00
     Day of year of orbit, Tomega = 265.00
     Time of perigee in seconds, Tzero = 0.0
     Start time in seconds = 0.0
     Integration time in seconds, Delta_t = 100.0
     End time in seconds = 86400.0
Orbital Period =5.581780e+003 seconds

Geomagnetic Transmission Function for this orbit
Rigidity (GV)   Exposure
    0.0200       0.0000
    0.0218       0.0000
```

**(many lines deleted here.  See distribution disk for complete file.)**

```
    0.4083       0.0000
    0.4450       0.0009
    0.4851       0.0028
    0.5287       0.0037
    0.5763       0.0059
    0.6282       0.0084
    0.6847       0.0094
    0.7464       0.0113
    0.8135       0.0136
    0.8867       0.0170
    0.9665       0.0188
    1.0535       0.0218
    1.1484       0.0275
    1.2517       0.0343
    1.3644       0.0418
    1.4872       0.0479
    1.6210       0.0548
    1.7669       0.0625
    1.9259       0.0713
    2.0992       0.0803
    2.2882       0.0901
    2.4941       0.1000
    2.7186       0.1111
    2.9632       0.1236
    3.2299       0.1369
    3.5206       0.1517
    3.8375       0.1684
    4.1829       0.1888
    4.5593       0.2117
    4.9697       0.2359
    5.4169       0.2607
```

| | |
|---|---|
| 5.9044 | 0.2860 |
| 6.4358 | 0.3109 |
| 7.0151 | 0.3356 |
| 7.6464 | 0.3614 |
| 8.3346 | 0.3899 |
| 9.0847 | 0.4229 |
| 9.9023 | 0.4575 |
| 10.7936 | 0.4920 |
| 11.7650 | 0.5250 |
| 12.8238 | 0.5536 |
| 13.9780 | 0.5776 |
| 15.2360 | 0.5976 |
| 16.6072 | 0.6144 |
| 18.1019 | 0.6282 |
| 19.7310 | 0.6393 |
| 21.5068 | 0.6483 |
| 23.4424 | 0.6556 |
| 25.5523 | 0.6612 |
| 27.8520 | 0.6654 |
| 30.3586 | 0.6687 |
| 33.0909 | 0.6710 |
| 36.0691 | 0.6726 |
| 39.3153 | 0.6737 |
| 42.8537 | 0.6743 |
| 46.7105 | 0.6747 |
| 50.9145 | 0.6749 |
| 55.4968 | 0.6749 |
| 60.4915 | 0.6750 |
| 65.9357 | 0.6750 |
| 71.8699 | 0.6750 |
| 78.3382 | 0.6750 |
| 85.3887 | 0.6750 |
| 93.0737 | 0.6750 |
| 101.4503 | 0.6750 |

```
Galactic Cosmic Ray Flux
Units:  particles/(m2 s sr MeV/nucleon)

Energy Z=  1.00     2.00     3.00     4.00     5.00     6.00     7.00     8.00
(MeV/n) M=  1.00     4.00     6.45     8.10    10.70    12.03    14.42    16.03
    10.0 1.00e-15 1.00e-15 1.00e-15 1.00e-15 1.00e-15 1.00e-15 1.00e-15 1.00e-15
    11.2 1.00e-15 1.00e-15 1.00e-15 1.00e-15 1.00e-15 1.00e-15 1.00e-15 1.00e-15
    12.6 1.00e-15 1.00e-15 1.00e-15 1.00e-15 1.00e-15 1.00e-15 1.00e-15 1.00e-15
    14.1 1.00e-15 1.00e-15 1.00e-15 1.00e-15 1.00e-15 1.00e-15 1.00e-15 1.00e-15
    15.8 1.00e-15 1.00e-15 1.00e-15 1.00e-15 1.00e-15 1.00e-15 1.00e-15 1.00e-15
    17.8 1.00e-15 1.00e-15 1.00e-15 1.00e-15 1.00e-15 1.00e-15 1.00e-15 1.00e-15
    19.9 1.00e-15 1.00e-15 4.66e-08 1.00e-15 6.66e-08 1.00e-15 1.00e-15 1.00e-15
    22.4 1.00e-15 7.45e-06 2.09e-07 2.20e-08 3.65e-07 1.82e-07 1.55e-07 1.59e-07
    25.1 1.00e-15 9.23e-05 5.76e-07 1.06e-07 1.02e-06 1.65e-06 5.11e-07 1.54e-06
    28.2 1.00e-15 2.62e-04 9.80e-07 2.92e-07 1.80e-06 4.67e-06 1.27e-06 4.37e-06
    31.6 1.00e-15 4.99e-04 1.31e-06 5.03e-07 2.41e-06 8.72e-06 1.93e-06 8.22e-06
    35.4 1.00e-15 6.67e-04 2.01e-06 6.74e-07 3.64e-06 1.17e-05 2.65e-06 1.10e-05
    39.7 1.00e-15 9.77e-04 2.92e-06 1.03e-06 5.31e-06 1.73e-05 4.02e-06 1.63e-05
    44.6 1.00e-15 1.42e-03 4.09e-06 1.50e-06 7.45e-06 2.52e-05 5.79e-06 2.38e-05
    50.0 1.00e-15 1.98e-03 4.93e-06 2.09e-06 9.04e-06 3.52e-05 7.74e-06 3.33e-05
    56.1 1.00e-15 2.42e-03 6.03e-06 2.52e-06 1.10e-05 4.30e-05 9.24e-06 4.08e-05
    63.0 1.00e-15 2.87e-03 7.49e-06 3.08e-06 1.36e-05 5.16e-05 1.14e-05 4.89e-05
    70.6 1.00e-15 3.48e-03 9.33e-06 3.82e-06 1.69e-05 6.30e-05 1.41e-05 5.98e-05
    79.2 1.00e-15 4.23e-03 1.18e-05 4.75e-06 2.12e-05 7.71e-05 1.73e-05 7.33e-05
    88.9 3.35e-04 5.16e-03 1.47e-05 5.99e-06 2.66e-05 9.51e-05 2.20e-05 9.04e-05
    99.7 1.50e-03 6.34e-03 1.71e-05 7.46e-06 3.07e-05 1.18e-04 2.65e-05 1.12e-04
   111.9 4.09e-03 7.13e-03 2.03e-05 8.64e-06 3.61e-05 1.33e-04 3.04e-05 1.27e-04
```

(many lines deleted here.  See distribution disk for complete file.)

```
  4977.3 2.96e-02 4.18e-03 1.93e-05 9.78e-06 2.48e-05 9.71e-05 2.38e-05 1.01e-04
  5583.9 2.49e-02 3.39e-03 1.50e-05 7.72e-06 1.94e-05 7.91e-05 1.90e-05 8.28e-05
  6264.4 2.07e-02 2.69e-03 1.14e-05 5.97e-06 1.48e-05 6.31e-05 1.48e-05 6.64e-05
  7027.9 1.71e-02 2.11e-03 8.61e-06 4.55e-06 1.12e-05 4.97e-05 1.14e-05 5.26e-05
  7884.4 1.41e-02 1.63e-03 6.38e-06 3.42e-06 8.32e-06 3.86e-05 8.62e-06 4.11e-05
  8845.3 1.16e-02 1.25e-03 4.68e-06 2.53e-06 6.12e-06 2.97e-05 6.45e-06 3.18e-05
  9923.3 9.42e-03 9.48e-04 3.40e-06 1.86e-06 4.47e-06 2.26e-05 4.78e-06 2.43e-05
 11132.7 7.52e-03 7.11e-04 2.44e-06 1.35e-06 3.22e-06 1.70e-05 3.51e-06 1.84e-05
 12489.5 5.89e-03 5.30e-04 1.74e-06 9.68e-07 2.30e-06 1.27e-05 2.55e-06 1.39e-05
 14011.6 4.54e-03 3.93e-04 1.23e-06 6.90e-07 1.64e-06 9.46e-06 1.85e-06 1.04e-05
 15719.3 3.44e-03 2.89e-04 8.62e-07 4.87e-07 1.15e-06 6.98e-06 1.32e-06 7.71e-06
 17635.1 2.58e-03 2.12e-04 6.03e-07 3.42e-07 8.08e-07 5.14e-06 9.45e-07 5.70e-06
 19784.3 1.92e-03 1.55e-04 4.18e-07 2.39e-07 5.63e-07 3.76e-06 6.71e-07 4.19e-06
 22195.5 1.41e-03 1.12e-04 2.89e-07 1.66e-07 3.90e-07 2.74e-06 4.74e-07 3.07e-06
 24900.6 1.04e-03 8.18e-05 1.99e-07 1.15e-07 2.71e-07 2.00e-06 3.35e-07 2.25e-06
 27935.3 7.54e-04 5.93e-05 1.37e-07 7.94e-08 1.87e-07 1.45e-06 2.36e-07 1.64e-06
 31339.9 5.48e-04 4.30e-05 9.43e-08 5.48e-08 1.29e-07 1.05e-06 1.66e-07 1.20e-06
 35159.5 3.98e-04 3.12e-05 6.50e-08 3.79e-08 8.93e-08 7.67e-07 1.17e-07 8.77e-07
 39444.5 2.89e-04 2.26e-05 4.47e-08 2.62e-08 6.17e-08 5.58e-07 8.24e-08 6.41e-07
 44251.8 2.11e-04 1.65e-05 3.11e-08 1.83e-08 4.31e-08 4.08e-07 5.85e-08 4.72e-07
 49645.0 1.53e-04 1.20e-05 2.15e-08 1.27e-08 2.99e-08 2.98e-07 4.14e-08 3.46e-07
```

| Energy | Z= 9.00 | 10.00 | 11.00 | 12.00 | 13.00 | 14.00 | 15.00 | 16.00 |
|--------|---------|-------|-------|-------|-------|-------|-------|-------|
| (MeV/n) | M= 19.0 | 20.66 | 23.00 | 24.36 | 26.87 | 28.18 | 31.00 | 32.35 |
| 10.0 | 1.00e-15 | 1.00e-15 | 1.00e-15 | 1.00e-15 | 1.00e-15 | 1.00e-15 | 1.00e-15 | 1.00e-15 |
| 11.2 | 1.00e-15 | 1.00e-15 | 1.00e-15 | 1.00e-15 | 1.00e-15 | 1.00e-15 | 1.00e-15 | 1.00e-15 |
| 12.6 | 1.00e-15 | 1.00e-15 | 1.00e-15 | 1.00e-15 | 1.00e-15 | 1.00e-15 | 1.00e-15 | 1.00e-15 |
| 14.1 | 1.00e-15 | 1.00e-15 | 1.00e-15 | 1.00e-15 | 1.00e-15 | 1.00e-15 | 1.00e-15 | 1.00e-15 |
| 15.8 | 1.00e-15 | 1.00e-15 | 1.00e-15 | 1.00e-15 | 1.00e-15 | 1.00e-15 | 1.00e-15 | 1.00e-15 |
| 17.8 | 1.00e-15 | 1.00e-15 | 1.00e-15 | 1.00e-15 | 1.00e-15 | 1.00e-15 | 1.00e-15 | 1.00e-15 |
| 19.9 | 4.74e-10 | 1.00e-15 | 1.00e-15 | 1.00e-15 | 1.00e-15 | 1.00e-15 | 1.00e-15 | 1.00e-15 |
| 22.4 | 1.77e-08 | 1.16e-07 | 2.29e-08 | 7.76e-08 | 1.80e-08 | 3.25e-08 | 2.52e-09 | 6.27e-09 |
| 25.1 | 5.12e-08 | 3.72e-07 | 6.88e-08 | 3.39e-07 | 5.77e-08 | 2.14e-07 | 8.11e-09 | 3.23e-08 |
| 28.2 | 1.03e-07 | 8.93e-07 | 1.50e-07 | 9.31e-07 | 1.38e-07 | 6.00e-07 | 1.95e-08 | 8.96e-08 |
| 31.6 | 1.39e-07 | 1.33e-06 | 2.08e-07 | 1.57e-06 | 2.06e-07 | 1.08e-06 | 2.92e-08 | 1.56e-07 |
| 35.4 | 2.04e-07 | 1.84e-06 | 2.98e-07 | 2.09e-06 | 2.86e-07 | 1.45e-06 | 4.07e-08 | 2.09e-07 |
| 39.7 | 3.01e-07 | 2.78e-06 | 4.44e-07 | 3.19e-06 | 4.31e-07 | 2.18e-06 | 6.17e-08 | 3.17e-07 |
| 44.6 | 4.28e-07 | 3.98e-06 | 6.34e-07 | 4.62e-06 | 6.20e-07 | 3.18e-06 | 8.91e-08 | 4.63e-07 |
| 50.0 | 5.39e-07 | 5.27e-06 | 8.14e-07 | 6.42e-06 | 8.21e-07 | 4.44e-06 | 1.19e-07 | 6.49e-07 |
| 56.1 | 6.50e-07 | 6.26e-06 | 9.72e-07 | 7.65e-06 | 9.79e-07 | 5.40e-06 | 1.43e-07 | 7.84e-07 |
| 63.0 | 8.09e-07 | 7.70e-06 | 1.21e-06 | 9.28e-06 | 1.21e-06 | 6.52e-06 | 1.78e-07 | 9.55e-07 |
| 70.6 | 1.01e-06 | 9.46e-06 | 1.49e-06 | 1.14e-05 | 1.49e-06 | 8.01e-06 | 2.22e-07 | 1.18e-06 |
| 79.2 | 1.26e-06 | 1.16e-05 | 1.85e-06 | 1.40e-05 | 1.84e-06 | 9.86e-06 | 2.77e-07 | 1.46e-06 |
| 88.9 | 1.60e-06 | 1.46e-05 | 2.34e-06 | 1.75e-05 | 2.33e-06 | 1.23e-05 | 3.56e-07 | 1.84e-06 |
| 99.7 | 1.87e-06 | 1.74e-05 | 2.76e-06 | 2.13e-05 | 2.79e-06 | 1.52e-05 | 4.33e-07 | 2.28e-06 |
| 111.9 | 2.19e-06 | 1.99e-05 | 3.20e-06 | 2.43e-05 | 3.21e-06 | 1.73e-05 | 5.07e-07 | 2.63e-06 |

(many lines deleted here.  See distribution disk for complete file.)

| | | | | | | | | |
|--------|---------|-------|-------|-------|-------|-------|-------|-------|
| 3142.0 | 4.47e-06 | 3.25e-05 | 5.95e-06 | 4.05e-05 | 6.62e-06 | 3.15e-05 | 1.52e-06 | 6.48e-06 |
| 3525.0 | 3.78e-06 | 2.78e-05 | 5.06e-06 | 3.49e-05 | 5.70e-06 | 2.72e-05 | 1.29e-06 | 5.51e-06 |
| 3954.6 | 3.17e-06 | 2.38e-05 | 4.27e-06 | 3.00e-05 | 4.88e-06 | 2.35e-05 | 1.08e-06 | 4.69e-06 |
| 4436.6 | 2.61e-06 | 2.00e-05 | 3.55e-06 | 2.54e-05 | 4.12e-06 | 2.00e-05 | 8.98e-07 | 3.94e-06 |
| 4977.3 | 2.12e-06 | 1.65e-05 | 2.90e-06 | 2.13e-05 | 3.42e-06 | 1.68e-05 | 7.35e-07 | 3.28e-06 |
| 5583.9 | 1.67e-06 | 1.34e-05 | 2.32e-06 | 1.74e-05 | 2.79e-06 | 1.38e-05 | 5.89e-07 | 2.67e-06 |
| 6264.4 | 1.30e-06 | 1.06e-05 | 1.82e-06 | 1.39e-05 | 2.22e-06 | 1.12e-05 | 4.63e-07 | 2.13e-06 |
| 7027.9 | 9.92e-07 | 8.34e-06 | 1.41e-06 | 1.10e-05 | 1.75e-06 | 8.88e-06 | 3.59e-07 | 1.68e-06 |
| 7884.4 | 7.48e-07 | 6.46e-06 | 1.08e-06 | 8.62e-06 | 1.36e-06 | 6.98e-06 | 2.75e-07 | 1.30e-06 |
| 8845.3 | 5.57e-07 | 4.94e-06 | 8.15e-07 | 6.66e-06 | 1.04e-06 | 5.41e-06 | 2.07e-07 | 1.00e-06 |
| 9923.3 | 4.11e-07 | 3.75e-06 | 6.10e-07 | 5.09e-06 | 7.89e-07 | 4.16e-06 | 1.55e-07 | 7.62e-07 |
| 11132.7 | 2.99e-07 | 2.81e-06 | 4.51e-07 | 3.86e-06 | 5.93e-07 | 3.17e-06 | 1.15e-07 | 5.73e-07 |
| 12489.5 | 2.17e-07 | 2.10e-06 | 3.31e-07 | 2.90e-06 | 4.42e-07 | 2.40e-06 | 8.41e-08 | 4.28e-07 |
| 14011.6 | 1.55e-07 | 1.56e-06 | 2.42e-07 | 2.17e-06 | 3.27e-07 | 1.80e-06 | 6.12e-08 | 3.18e-07 |
| 15719.3 | 1.10e-07 | 1.14e-06 | 1.75e-07 | 1.61e-06 | 2.40e-07 | 1.34e-06 | 4.42e-08 | 2.34e-07 |
| 17635.1 | 7.82e-08 | 8.40e-07 | 1.26e-07 | 1.19e-06 | 1.75e-07 | 9.97e-07 | 3.18e-08 | 1.72e-07 |
| 19784.3 | 5.50e-08 | 6.12e-07 | 9.01e-08 | 8.78e-07 | 1.27e-07 | 7.36e-07 | 2.27e-08 | 1.26e-07 |
| 22195.5 | 3.84e-08 | 4.45e-07 | 6.42e-08 | 6.43e-07 | 9.19e-08 | 5.42e-07 | 1.61e-08 | 9.12e-08 |
| 24900.6 | 2.69e-08 | 3.23e-07 | 4.57e-08 | 4.71e-07 | 6.63e-08 | 3.98e-07 | 1.15e-08 | 6.63e-08 |
| 27935.3 | 1.87e-08 | 2.34e-07 | 3.25e-08 | 3.44e-07 | 4.77e-08 | 2.92e-07 | 8.12e-09 | 4.80e-08 |
| 31339.9 | 1.30e-08 | 1.70e-07 | 2.31e-08 | 2.51e-07 | 3.43e-08 | 2.14e-07 | 5.76e-09 | 3.48e-08 |
| 35159.5 | 9.07e-09 | 1.23e-07 | 1.64e-08 | 1.84e-07 | 2.47e-08 | 1.57e-07 | 4.08e-09 | 2.52e-08 |
| 39444.5 | 6.32e-09 | 8.91e-08 | 1.17e-08 | 1.34e-07 | 1.78e-08 | 1.15e-07 | 2.89e-09 | 1.83e-08 |
| 44251.8 | 4.44e-09 | 6.50e-08 | 8.35e-09 | 9.90e-08 | 1.29e-08 | 8.52e-08 | 2.07e-09 | 1.34e-08 |
| 49645.0 | 3.11e-09 | 4.73e-08 | 5.96e-09 | 7.26e-08 | 9.34e-09 | 6.27e-08 | 1.47e-09 | 9.73e-09 |

| Energy | Z= 17.00 | 18.00 | 19.00 | 20.00 | 21.00 | 22.00 | 23.00 | 24.00 |
|---|---|---|---|---|---|---|---|---|
| (MeV/n) | M= 35.79 | 37.22 | 39.91 | 41.60 | 45.00 | 4$\overline{\phantom{.}}$.19 | 50.35 | 52.08 |
| 10.0 | 1.00e-15 | 1.00e-15 | 1.00e-15 | 1.00e-15 | 1.00e-15 | 1.00e-15 | 1.00e-15 | 1.00e-15 |
| 11.2 | 1.00e-15 | 1.00e-15 | 1.00e-15 | 1.00e-15 | 1.00e-15 | 1.00e-15 | 1.00e-15 | 1.00e-15 |
| 12.6 | 1.00e-15 | 1.00e-15 | 1.00e-15 | 1.00e-15 | 1.00e-15 | 1.00e-15 | 1.00e-15 | 1.00e-15 |
| 14.1 | 1.00e-15 | 1.00e-15 | 1.00e-15 | 1.00e-15 | 1.00e-15 | 1.00e-15 | 1.00e-15 | 1.00e-15 |
| 15.8 | 1.00e-15 | 1.00e-15 | 1.00e-15 | 1.00e-15 | 1.00e-15 | 1.00e-15 | 1.00e-15 | 1.00e-15 |
| 17.8 | 1.00e-15 | 1.00e-15 | 1.00e-15 | 1.00e-15 | 1.00e-15 | 1.00e-15 | 1.00e-15 | 1.00e-15 |
| 19.9 | 1.00e-15 | 1.00e-15 | 1.00e-15 | 1.00e-15 | 9.12e-10 | 4.37e-09 | 5.16e-09 | 9.00e-09 |
| 22.4 | 2.65e-09 | 5.09e-09 | 4.53e-09 | 1.14e-08 | 4.69e-09 | 2.15e-08 | 1.66e-08 | 3.13e-08 |
| 25.1 | 7.77e-09 | 1.63e-08 | 1.34e-08 | 3.52e-08 | 1.31e-08 | 5.96e-08 | 4.00e-08 | 8.35e-08 |
| 28.2 | 1.61e-08 | 3.91e-08 | 2.83e-08 | 7.99e-08 | 2.28e-08 | 1.03e-07 | 5.99e-08 | 1.32e-07 |
| 31.6 | 2.19e-08 | 5.82e-08 | 3.87e-08 | 1.15e-07 | 3.07e-08 | 1.38e-07 | 8.28e-08 | 1.79e-07 |
| 35.4 | 3.20e-08 | 8.12e-08 | 5.63e-08 | 1.62e-07 | 4.65e-08 | 2.09e-07 | 1.25e-07 | 2.73e-07 |
| 39.7 | 4.76e-08 | 1.23e-07 | 8.38e-08 | 2.44e-07 | 6.80e-08 | 3.05e-07 | 1.79e-07 | 3.94e-07 |
| 44.6 | 6.83e-08 | 1.78e-07 | 1.20e-07 | 3.50e-07 | 9.56e-08 | 4.27e-07 | 2.38e-07 | 5.36e-07 |
| 50.0 | 8.71e-08 | 2.37e-07 | 1.54e-07 | 4.57e-07 | 1.16e-07 | 5.15e-07 | 2.84e-07 | 6.39e-07 |
| 56.1 | 1.06e-07 | 2.84e-07 | 1.87e-07 | 5.48e-07 | 1.42e-07 | 6.26e-07 | 3.49e-07 | 7.82e-07 |
| 63.0 | 1.33e-07 | 3.54e-07 | 2.34e-07 | 6.82e-07 | 1.77e-07 | 7.75e-07 | 4.31e-07 | 9.64e-07 |
| 70.6 | 1.67e-07 | 4.42e-07 | 2.94e-07 | 8.48e-07 | 2.20e-07 | 9.61e-07 | 5.30e-07 | 1.19e-06 |
| 79.2 | 2.12e-07 | 5.51e-07 | 3.71e-07 | 1.05e-06 | 2.79e-07 | 1.21e-06 | 6.70e-07 | 1.49e-06 |
| 88.9 | 2.73e-07 | 7.07e-07 | 4.79e-07 | 1.34e-06 | 3.51e-07 | 1.51e-06 | 8.07e-07 | 1.82e-06 |
| 99.7 | 3.27e-07 | 8.60e-07 | 5.74e-07 | 1.61e-06 | 4.10e-07 | 1.74e-06 | 9.27e-07 | 2.08e-06 |
| 111.9 | 3.91e-07 | 1.01e-06 | 6.84e-07 | 1.88e-06 | 4.88e-07 | 2.05e-06 | 1.10e-06 | 2.45e-06 |

(many lines deleted here.  See distribution disk for complete file.)

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| 3142.0 | 1.48e-06 | 2.82e-06 | 2.08e-06 | 4.20e-06 | 9.29e-07 | 3.21e-06 | 1.30e-06 | 2.90e-06 |
| 3525.0 | 1.24e-06 | 2.35e-06 | 1.73e-06 | 3.55e-06 | 7.63e-07 | 2.71e-06 | 1.11e-06 | 2.50e-06 |
| 3954.6 | 1.04e-06 | 1.96e-06 | 1.44e-06 | 3.00e-06 | 6.22e-07 | 2.27e-06 | 9.32e-07 | 2.13e-06 |
| 4436.6 | 8.58e-07 | 1.62e-06 | 1.18e-06 | 2.50e-06 | 5.02e-07 | 1.87e-06 | 7.74e-07 | 1.79e-06 |
| 4977.3 | 7.03e-07 | 1.32e-06 | 9.63e-07 | 2.06e-06 | 4.02e-07 | 1.52e-06 | 6.31e-07 | 1.47e-06 |
| 5583.9 | 5.66e-07 | 1.05e-06 | 7.70e-07 | 1.67e-06 | 3.19e-07 | 1.22e-06 | 5.05e-07 | 1.18e-06 |
| 6264.4 | 4.48e-07 | 8.28e-07 | 6.05e-07 | 1.33e-06 | 2.51e-07 | 9.62e-07 | 3.97e-07 | 9.35e-07 |
| 7027.9 | 3.50e-07 | 6.42e-07 | 4.70e-07 | 1.04e-06 | 1.95e-07 | 7.49e-07 | 3.09e-07 | 7.31e-07 |
| 7884.4 | 2.70e-07 | 4.91e-07 | 3.59e-07 | 8.07e-07 | 1.49e-07 | 5.75e-07 | 2.37e-07 | 5.64e-07 |
| 8845.3 | 2.05e-07 | 3.70e-07 | 2.71e-07 | 6.17e-07 | 1.13e-07 | 4.36e-07 | 1.80e-07 | 4.29e-07 |
| 9923.3 | 1.55e-07 | 2.76e-07 | 2.03e-07 | 4.68e-07 | 8.45e-08 | 3.28e-07 | 1.35e-07 | 3.24e-07 |
| 11132.7 | 1.15e-07 | 2.04e-07 | 1.50e-07 | 3.51e-07 | 6.26e-08 | 2.43e-07 | 1.01e-07 | 2.42e-07 |
| 12489.5 | 8.51e-08 | 1.50e-07 | 1.10e-07 | 2.61e-07 | 4.60e-08 | 1.79e-07 | 7.41e-08 | 1.80e-07 |
| 14011.6 | 6.23e-08 | 1.09e-07 | 7.97e-08 | 1.93e-07 | 3.35e-08 | 1.31e-07 | 5.43e-08 | 1.32e-07 |
| 15719.3 | 4.52e-08 | 7.86e-08 | 5.74e-08 | 1.41e-07 | 2.42e-08 | 9.52e-08 | 3.94e-08 | 9.65e-08 |
| 17635.1 | 3.26e-08 | 5.65e-08 | 4.12e-08 | 1.03e-07 | 1.74e-08 | 6.87e-08 | 2.84e-08 | 7.01e-08 |
| 19784.3 | 2.33e-08 | 4.04e-08 | 2.93e-08 | 7.49e-08 | 1.24e-08 | 4.92e-08 | 2.04e-08 | 5.06e-08 |
| 22195.5 | 1.65e-08 | 2.87e-08 | 2.07e-08 | 5.41e-08 | 8.81e-09 | 3.50e-08 | 1.45e-08 | 3.63e-08 |
| 24900.6 | 1.17e-08 | 2.05e-08 | 1.46e-08 | 3.91e-08 | 6.24e-09 | 2.49e-08 | 1.03e-08 | 2.60e-08 |
| 27935.3 | 8.28e-09 | 1.45e-08 | 1.03e-08 | 2.81e-08 | 4.41e-09 | 1.76e-08 | 7.34e-09 | 1.86e-08 |
| 31339.9 | 5.85e-09 | 1.03e-08 | 7.24e-09 | 2.03e-08 | 3.11e-09 | 1.25e-08 | 5.21e-09 | 1.33e-08 |
| 35159.5 | 4.14e-09 | 7.31e-09 | 5.10e-09 | 1.46e-08 | 2.20e-09 | 8.87e-09 | 3.70e-09 | 9.48e-09 |
| 39444.5 | 2.93e-09 | 5.19e-09 | 3.59e-09 | 1.05e-08 | 1.55e-09 | 6.29e-09 | 2.63e-09 | 6.78e-09 |
| 44251.8 | 2.09e-09 | 3.72e-09 | 2.55e-09 | 7.63e-09 | 1.11e-09 | 4.50e-09 | 1.88e-09 | 4.89e-09 |
| 49645.0 | 1.48e-09 | 2.65e-09 | 1.80e-09 | 5.52e-09 | 7.85e-10 | 3.20e-09 | 1.34e-09 | 3.51e-09 |

| Energy | Z= 25.00 | 26.00 | 27.00 | 28.00 |
|---|---|---|---|---|
| (MeV/n) | M= 53.83 | 55.88 | 58.23 | 58.77 |
| 10.0 | 1.00e-15 | 1.00e-15 | 1.00e-15 | 1.00e-15 |
| 11.2 | 1.00e-15 | 1.00e-15 | 1.00e-15 | 1.00e-15 |
| 12.6 | 1.00e-15 | 1.00e-15 | 1.00e-15 | 1.00e-15 |
| 14.1 | 1.00e-15 | 1.00e-15 | 1.00e-15 | 1.00e-15 |
| 15.8 | 1.00e-15 | 1.00e-15 | 1.00e-15 | 1.00e-15 |
| 17.8 | 1.00e-15 | 1.00e-15 | 1.00e-15 | 1.00e-15 |
| 19.9 | 3.52e-09 | 3.16e-08 | 1.36e-10 | 1.00e-15 |
| 22.4 | 1.49e-08 | 1.44e-07 | 5.51e-10 | 3.96e-09 |
| 25.1 | 4.11e-08 | 3.97e-07 | 1.52e-09 | 1.17e-08 |
| 28.2 | 6.90e-08 | 6.77e-07 | 2.52e-09 | 2.48e-08 |
| 31.6 | 9.22e-08 | 9.07e-07 | 3.39e-09 | 3.39e-08 |
| 35.4 | 1.41e-07 | 1.38e-06 | 5.22e-09 | 4.90e-08 |
| 39.7 | 2.05e-07 | 2.01e-06 | 7.61e-09 | 7.26e-08 |
| 44.6 | 2.85e-07 | 2.81e-06 | 1.06e-08 | 1.03e-07 |
| 50.0 | 3.41e-07 | 3.38e-06 | 1.28e-08 | 1.32e-07 |
| 56.1 | 4.15e-07 | 4.12e-06 | 1.57e-08 | 1.58e-07 |
| 63.0 | 5.13e-07 | 5.10e-06 | 1.96e-08 | 1.96e-07 |
| 70.6 | 6.34e-07 | 6.32e-06 | 2.45e-08 | 2.42e-07 |
| 79.2 | 7.96e-07 | 7.93e-06 | 3.12e-08 | 3.01e-07 |
| 88.9 | 9.83e-07 | 9.83e-06 | 3.89e-08 | 3.80e-07 |
| 99.7 | 1.13e-06 | 1.13e-05 | 4.53e-08 | 4.45e-07 |
| 111.9 | 1.32e-06 | 1.32e-05 | 5.39e-08 | 5.16e-07 |

(many lines deleted here.  See distribution disk for complete file.)

| 3142.0 | 2.22e-06 | 2.39e-05 | 1.17e-07 | 1.02e-06 |
|---|---|---|---|---|
| 3525.0 | 1.93e-06 | 2.09e-05 | 1.01e-07 | 8.95e-07 |
| 3954.6 | 1.65e-06 | 1.82e-05 | 8.74e-08 | 7.80e-07 |
| 4436.6 | 1.40e-06 | 1.55e-05 | 7.42e-08 | 6.70e-07 |
| 4977.3 | 1.16e-06 | 1.30e-05 | 6.18e-08 | 5.66e-07 |
| 5583.9 | 9.43e-07 | 1.07e-05 | 5.04e-08 | 4.68e-07 |
| 6264.4 | 7.51e-07 | 8.68e-06 | 4.04e-08 | 3.80e-07 |
| 7027.9 | 5.91e-07 | 6.94e-06 | 3.19e-08 | 3.05e-07 |
| 7884.4 | 4.58e-07 | 5.47e-06 | 2.49e-08 | 2.42e-07 |
| 8845.3 | 3.51e-07 | 4.27e-06 | 1.93e-08 | 1.89e-07 |
| 9923.3 | 2.67e-07 | 3.31e-06 | 1.48e-08 | 1.47e-07 |
| 11132.7 | 2.01e-07 | 2.54e-06 | 1.12e-08 | 1.13e-07 |
| 12489.5 | 1.49e-07 | 1.94e-06 | 8.43e-09 | 8.65e-08 |
| 14011.6 | 1.11e-07 | 1.47e-06 | 6.30e-09 | 6.57e-08 |
| 15719.3 | 8.10e-08 | 1.10e-06 | 4.68e-09 | 4.95e-08 |
| 17635.1 | 5.91e-08 | 8.28e-07 | 3.46e-09 | 3.72e-08 |
| 19784.3 | 4.28e-08 | 6.17e-07 | 2.54e-09 | 2.78e-08 |
| 22195.5 | 3.08e-08 | 4.58e-07 | 1.86e-09 | 2.07e-08 |
| 24900.6 | 2.21e-08 | 3.40e-07 | 1.36e-09 | 1.54e-08 |
| 27935.3 | 1.58e-08 | 2.52e-07 | 9.90e-10 | 1.14e-08 |
| 31339.9 | 1.13e-08 | 1.86e-07 | 7.22e-10 | 8.47e-09 |
| 35159.5 | 8.12e-09 | 1.38e-07 | 5.27e-10 | 6.28e-09 |
| 39444.5 | 5.82e-09 | 1.02e-07 | 3.84e-10 | 4.66e-09 |
| 44251.8 | 4.21e-09 | 7.62e-08 | 2.82e-10 | 3.48e-09 |
| 49645.0 | 3.02e-09 | 5.66e-08 | 2.06e-10 | 2.59e-09 |

```
Anomalous Component Flux    Units:   particles/(m2 s sr MeV/nuc)

     AC E Z=  1.00      1.00      1.00      1.00
   (MeV/n) M=  4.00     14.00     16.00     20.00
     10.0 6.67e-03 1.69e-03 1.54e-02 9.59e-04
     10.7 8.10e-03 1.59e-03 1.42e-02 8.60e-04
     11.5 9.64e-03 1.48e-03 1.29e-02 7.64e-04
     12.4 1.12e-02 1.36e-03 1.17e-02 6.73e-04
     13.3 1.26e-02 1.24e-03 1.04e-02 5.88e-04
     14.3 1.30e-02 1.13e-03 9.29e-03 5.10e-04
     15.4 1.33e-02 1.01e-03 8.19e-03 4.39e-04
     16.5 1.39e-02 8.93e-04 7.18e-03 3.75e-04
     17.8 1.43e-02 7.86e-04 6.23e-03 3.18e-04
     19.1 1.47e-02 6.86e-04 5.36e-03 2.68e-04
     20.5 1.49e-02 5.93e-04 4.57e-03 2.24e-04
     22.0 1.50e-02 5.09e-04 3.87e-03 1.87e-04
     23.7 1.52e-02 4.33e-04 3.25e-03 1.55e-04
     25.5 1.51e-02 3.64e-04 2.71e-03 1.27e-04
     27.4 1.44e-02 3.03e-04 2.23e-03 1.04e-04
     29.4 1.33e-02 2.48e-04 1.82e-03 8.37e-05
     31.6 1.22e-02 2.00e-04 1.46e-03 6.68e-05
     33.9 1.11e-02 1.57e-04 1.15e-03 5.23e-05
     36.5 1.00e-02 1.19e-04 8.81e-04 3.98e-05
     39.2 9.28e-03 8.64e-05 6.45e-04 2.92e-05
     42.1 8.40e-03 5.99e-05 4.48e-04 2.01e-05
     45.2 7.49e-03 3.97e-05 2.95e-04 1.31e-05
     48.6 6.57e-03 2.56e-05 1.88e-04 8.19e-06
```

**(many lines deleted here.  See distribution disk for complete file.)**

```
    451.2 2.18e-07 1.38e-15 7.05e-15 1.00e-15
    484.9 1.41e-07 1.00e-15 2.91e-15 1.00e-15
    521.0 9.11e-08 1.00e-15 1.20e-15 1.00e-15
    559.8 5.84e-08 1.00e-15 1.00e-15 1.00e-15
    601.5 3.72e-08 1.00e-15 1.00e-15 1.00e-15
    646.4 2.36e-08 1.00e-15 1.00e-15 1.00e-15
    694.5 1.50e-08 1.00e-15 1.00e-15 1.00e-15
    746.3 9.42e-09 1.00e-15 1.00e-15 1.00e-15
    801.9 5.90e-09 1.00e-15 1.00e-15 1.00e-15
    861.7 3.66e-09 1.00e-15 1.00e-15 1.00e-15
    925.9 2.28e-09 1.00e-15 1.00e-15 1.00e-15
    994.9 1.40e-09 1.00e-15 1.00e-15 1.00e-15
   1069.0 8.63e-10 1.00e-15 1.00e-15 1.00e-15
   1148.7 5.27e-10 1.00e-15 1.00e-15 1.00e-15
   1234.3 3.23e-10 1.00e-15 1.00e-15 1.00e-15
   1326.3 1.98e-10 1.00e-15 1.00e-15 1.00e-15
   1425.1 1.21e-10 1.00e-15 1.00e-15 1.00e-15
   1531.3 7.40e-11 1.00e-15 1.00e-15 1.00e-15
   1645.4 4.51e-11 1.00e-15 1.00e-15 1.00e-15
   1768.0 2.75e-11 1.00e-15 1.00e-15 1.00e-15
   1899.8 1.67e-11 1.00e-15 1.00e-15 1.00e-15
   2041.4 1.01e-11 1.00e-15 1.00e-15 1.00e-15
```

File: SOLARMIN.ORB    Orbit listing file for solar minimum validation run.


Orbit Listing Output File from CHIME V3.5

Model file name: SOLARMIN.CHM       Dated: Mon Jan 20 09:05:22 1997
Solar minimum conditions, phi = 400 MV, no solar particle fluxes
Typical space station/MIR orbit: 430 km altitude, 51 deg inclination


Specification for orbit and geomagnetic shielding calculation:
    Perigee altitude in kilometers = 430
    Apogee altitude in kilometers = 430
    Perigee angle in degrees, Beta = 0.00
    Inclination angle in degrees = 51.00
    Longitude of ascending node in degrees = 0.00
    Day of year of orbit, Tomega = 265.00
    Time of perigee in seconds, Tzero = 0.0
    Start time in seconds = 0.0
    Integration time in seconds, Delta_t = 100.0
    End time in seconds = 86400.0
Orbital Period =5.581780e+003 seconds

| Time(s) | Radius(km) | Lat(deg) | Lon(deg) | X (km) | Y (km) | Z (km) |
|---|---|---|---|---|---|---|
| 0.0 | 6806.9 | 0.00 | 0.00 | 6806.9 | 0.0 | 0.0 |
| 100.0 | 6806.7 | 5.00 | 3.64 | 6767.1 | 430.9 | 593.7 |
| 200.0 | 6806.3 | 9.98 | 7.35 | 6648.2 | 857.5 | 1179.8 |
| 300.0 | 6805.6 | 14.91 | 11.18 | 6451.6 | 1275.5 | 1750.9 |
| 400.0 | 6804.7 | 19.75 | 15.21 | 6179.8 | 1680.7 | 2299.6 |
| 500.0 | 6803.6 | 24.48 | 19.52 | 5836.0 | 2069.2 | 2819.1 |
| 600.0 | 6802.3 | 29.05 | 24.19 | 5424.4 | 2437.0 | 3302.7 |
| 700.0 | 6801.0 | 33.41 | 29.32 | 4949.9 | 2780.5 | 3744.4 |
| 800.0 | 6799.7 | 37.49 | 35.02 | 4418.2 | 3096.3 | 4138.6 |
| 900.0 | 6798.5 | 41.23 | 41.40 | 3835.6 | 3381.3 | 4480.4 |
| 1000.0 | 6797.4 | 44.52 | 48.54 | 3208.9 | 3632.6 | 4765.6 |
| 1100.0 | 6796.4 | 47.25 | 56.51 | 2545.7 | 3847.7 | 4990.6 |
| 1200.0 | 6795.7 | 49.31 | 65.27 | 1853.5 | 4024.5 | 5152.7 |
| 1300.0 | 6795.3 | 50.58 | 74.67 | 1140.5 | 4161.2 | 5249.8 |
| 1400.0 | 6795.2 | 51.00 | 84.43 | 415.0 | 4256.2 | 5280.8 |
| 1500.0 | 6795.3 | 50.52 | 94.18 | -314.7 | 4308.6 | 5245.3 |
| 1600.0 | 6795.8 | 49.19 | 103.54 | -1040.0 | 4317.7 | 5143.7 |
| 1700.0 | 6796.5 | 47.08 | 112.25 | -1752.6 | 4283.3 | 4977.4 |
| 1800.0 | 6797.4 | 44.31 | 120.16 | -2444.2 | 4205.4 | 4748.2 |
| 1900.0 | 6798.5 | 40.99 | 127.26 | -3106.8 | 4084.7 | 4459.1 |
| 2000.0 | 6799.8 | 37.23 | 133.58 | -3732.6 | 3922.1 | 4113.6 |
| 2100.0 | 6801.1 | 33.12 | 139.24 | -4314.5 | 3719.0 | 3716.0 |
| 2200.0 | 6802.4 | 28.74 | 144.34 | -4845.6 | 3477.3 | 3271.3 |
| 2300.0 | 6803.6 | 24.16 | 148.98 | -5319.7 | 3199.0 | 2785.1 |
| 2400.0 | 6804.7 | 19.43 | 153.27 | -5731.3 | 2886.8 | 2263.4 |
| 2500.0 | 6805.7 | 14.58 | 157.28 | -6075.5 | 2543.7 | 1712.9 |
| 2600.0 | 6806.3 | 9.65 | 161.10 | -6348.5 | 2173.0 | 1140.6 |
| 2700.0 | 6806.8 | 4.67 | 164.80 | -6547.0 | 1778.3 | 553.8 |
| 2800.0 | 6806.9 | -0.34 | 168.45 | -6668.8 | 1363.4 | -40.2 |

| | | | | | | |
|---|---|---|---|---|---|---|
| 2900.0 | 6806.7 | -5.34 | 172.09 | -6712.7 | 932.5 | -633.6 |
| 3000.0 | 6806.3 | -10.32 | 175.80 | -6678.3 | 490.0 | -1218.9 |
| 3100.0 | 6805.5 | -15.24 | 179.65 | -6566.1 | 40.3 | -1788.7 |
| 3200.0 | 6804.6 | -20.08 | 183.70 | -6377.9 | -412.0 | -2335.7 |
| 3300.0 | 6803.5 | -24.79 | 188.03 | -6115.9 | -862.3 | -2853.0 |
| 3400.0 | 6802.2 | -29.35 | 192.72 | -5783.6 | -1305.9 | -3334.0 |
| 3500.0 | 6800.9 | -33.69 | 197.89 | -5385.0 | -1738.3 | -3772.6 |
| 3600.0 | 6799.6 | -37.76 | 203.63 | -4925.1 | -2155.0 | -4163.4 |
| 3700.0 | 6798.4 | -41.46 | 210.06 | -4409.5 | -2551.6 | -4501.5 |
| 3800.0 | 6797.3 | -44.72 | 217.26 | -3844.4 | -2923.9 | -4782.7 |
| 3900.0 | 6796.4 | -47.41 | 225.28 | -3236.4 | -3268.1 | -5003.6 |
| 4000.0 | 6795.7 | -49.42 | 234.09 | -2592.9 | -3580.5 | -5161.3 |
| 4100.0 | 6795.3 | -50.64 | 243.52 | -1921.2 | -3857.5 | -5254.0 |
| 4200.0 | 6795.2 | -51.00 | 253.29 | -1229.3 | -4096.3 | -5280.5 |
| 4300.0 | 6795.4 | -50.46 | 263.03 | -525.3 | -4293.9 | -5240.5 |
| 4400.0 | 6795.8 | -49.07 | 272.35 | 182.9 | -4448.2 | -5134.5 |
| 4500.0 | 6796.5 | -46.92 | 281.01 | 886.9 | -4557.1 | -4963.8 |
| 4600.0 | 6797.5 | -44.10 | 288.87 | 1578.7 | -4619.1 | -4730.5 |
| 4700.0 | 6798.6 | -40.75 | 295.91 | 2250.4 | -4633.1 | -4437.5 |
| 4800.0 | 6799.9 | -36.96 | 302.18 | 2894.2 | -4598.7 | -4088.3 |
| 4900.0 | 6801.2 | -32.83 | 307.80 | 3502.7 | -4515.6 | -3687.4 |
| 5000.0 | 6802.5 | -28.44 | 312.86 | 4068.9 | -4384.3 | -3239.7 |
| 5100.0 | 6803.7 | -23.85 | 317.48 | 4586.4 | -4205.7 | -2750.9 |
| 5200.0 | 6804.8 | -19.10 | 321.74 | 5049.3 | -3981.3 | -2227.1 |
| 5300.0 | 6805.7 | -14.25 | 325.75 | 5452.2 | -3712.9 | -1674.9 |
| 5400.0 | 6806.4 | -9.31 | 329.56 | 5790.7 | -3403.1 | -1101.4 |
| 5500.0 | 6806.8 | -4.33 | 333.25 | 6061.0 | -3054.8 | -513.8 |
| 5600.0 | 6806.9 | 0.68 | 336.89 | 6260.3 | -2671.4 | 80.4 |
| 5700.0 | 6806.7 | 5.68 | 340.54 | 6386.3 | -2256.6 | 673.5 |

(lines deleted to save space - full file is provided on distribution disk)

| | | | | | | |
|---|---|---|---|---|---|---|
| 84500.0 | 6801.0 | 33.52 | 35.47 | 4617.9 | 3290.3 | 3755.4 |
| 84600.0 | 6799.7 | 37.59 | 41.19 | 4054.7 | 3547.8 | 4148.2 |
| 84700.0 | 6798.4 | 41.32 | 47.58 | 3444.3 | 3769.3 | 4488.6 |
| 84800.0 | 6797.3 | 44.59 | 54.75 | 2793.9 | 3952.7 | 4772.3 |
| 84900.0 | 6796.4 | 47.31 | 62.74 | 2111.0 | 4096.2 | 4995.7 |
| 85000.0 | 6795.7 | 49.35 | 71.52 | 1403.6 | 4198.5 | 5156.0 |
| 85100.0 | 6795.3 | 50.61 | 80.93 | 679.9 | 4258.7 | 5251.5 |
| 85200.0 | 6795.2 | 51.00 | 90.69 | -51.7 | 4276.2 | 5280.7 |
| 85300.0 | 6795.3 | 50.50 | 100.43 | -782.7 | 4250.9 | 5243.5 |
| 85400.0 | 6795.8 | 49.15 | 109.78 | -1504.7 | 4182.9 | 5140.2 |
| 85500.0 | 6796.5 | 47.02 | 118.47 | -2209.2 | 4073.0 | 4972.2 |
| 85600.0 | 6797.5 | 44.23 | 126.37 | -2888.1 | 3922.2 | 4741.4 |
| 85700.0 | 6798.6 | 40.89 | 133.44 | -3533.4 | 3731.8 | 4450.8 |
| 85800.0 | 6799.8 | 37.12 | 139.74 | -4137.7 | 3503.7 | 4103.8 |
| 85900.0 | 6801.1 | 33.01 | 145.38 | -4693.8 | 3239.9 | 3705.0 |
| 86000.0 | 6802.4 | 28.63 | 150.47 | -5195.1 | 2943.1 | 3259.1 |
| 86100.0 | 6803.7 | 24.04 | 155.10 | -5635.9 | 2616.0 | 2771.9 |
| 86200.0 | 6804.8 | 19.30 | 159.38 | -6010.8 | 2261.9 | 2249.4 |
| 86300.0 | 6805.7 | 14.45 | 163.39 | -6315.3 | 1884.1 | 1698.2 |
| 86400.0 | 6806.4 | 9.52 | 167.21 | -6546.0 | 1486.3 | 1125.4 |

## File: SOLARMIN.LET    LET spectrum listing file for solar minimum validation run.


LET Spectrum Output File from CHIME V3.5

Model file name: SOLARMIN.CHM        Dated: Mon Jan 20 09:05:22 1997
Solar minimum conditions, phi = 400 MV, no solar particle fluxes
Typical space station/MIR orbit: 430 km altitude, 51 deg inclination

Galactic cosmic ray spectrum for level of solar modulation phi = 400 MV

No solar flare heavy ion enhancement included.

Geomagnetic shielding effects included.


Specification for orbit and geomagnetic shielding calculation:
    Perigee altitude in kilometers = 430
    Apogee altitude in kilometers = 430
    Perigee angle in degrees, Beta = 0.00
    Inclination angle in degrees = 51.00
    Longitude of ascending node in degrees = 0.00
    Day of year of orbit, Tomega = 265.00
    Time of perigee in seconds, Tzero = 0.0
    Start time in seconds = 0.0
    Integration time in seconds, Delta_t = 100.0
    End time in seconds = 86400.0
Orbital Period =5.581780e+003 seconds


Average Integral Linear Energy Transfer Spectrum
Shield thickness = 1.0000e+003 mg/cm^2 = 1.0000e+003 mg/cm2
Sensitive region = 1.0000e+001 microns Si = 2.3300e+000 mg/cm2
Elements used with atomic number Z = 1 to 92

| Linear E Xfer | Interplanetary | GeoMag-shielded |
|---|---|---|
| LET(MeV/mg/cm2) | Flux/(m2 s sr) | Flux/(m2 s sr) |
| 1.0000e-002 | 2.2092e+002 | 1.2649e+001 |
| 1.2068e-002 | 1.6404e+002 | 9.8221e+000 |
| 1.4563e-002 | 1.2562e+002 | 8.3053e+000 |
| 1.7575e-002 | 9.8910e+001 | 7.3724e+000 |
| 2.1210e-002 | 8.1164e+001 | 6.9994e+000 |
| 2.5595e-002 | 6.9111e+001 | 6.7624e+000 |
| 3.0888e-002 | 6.0384e+001 | 6.5217e+000 |
| 3.7276e-002 | 5.4292e+001 | 6.4106e+000 |
| 4.4984e-002 | 4.8598e+001 | 5.9804e+000 |
| 5.4287e-002 | 4.4006e+001 | 5.7448e+000 |
| 6.5513e-002 | 3.6540e+001 | 4.4282e+000 |
| 7.9060e-002 | 3.1393e+001 | 4.0161e+000 |
| 9.5410e-002 | 2.6725e+001 | 3.5547e+000 |
| 1.1514e-001 | 2.0007e+001 | 2.1887e+000 |
| 1.3895e-001 | 1.5746e+001 | 1.8366e+000 |
| 1.6768e-001 | 1.2752e+001 | 1.5473e+000 |

| | | |
|---|---|---|
| 2.0236e-001 | 1.0383e+001 | 1.3517e+000 |
| 2.4421e-001 | 8.3507e+000 | 1.0557e+000 |
| 2.9471e-001 | 6.6484e+000 | 8.7120e-001 |
| 3.5565e-001 | 5.0303e+000 | 6.1101e-001 |
| 4.2919e-001 | 3.9893e+000 | 5.1003e-001 |
| 5.1795e-001 | 3.2499e+000 | 4.4814e-001 |
| 6.2506e-001 | 2.7066e+000 | 3.9595e-001 |
| 7.5431e-001 | 2.2557e+000 | 3.4487e-001 |
| 9.1030e-001 | 1.8865e+000 | 2.9744e-001 |
| 1.0985e+000 | 1.4272e+000 | 1.7608e-001 |
| 1.3257e+000 | 7.8438e-001 | 4.9727e-002 |
| 1.5999e+000 | 4.9473e-001 | 2.3693e-002 |
| 1.9307e+000 | 3.1967e-001 | 1.2477e-002 |
| 2.3300e+000 | 2.0828e-001 | 6.8865e-003 |
| 2.8118e+000 | 1.3612e-001 | 3.9065e-003 |
| 3.3932e+000 | 8.8986e-002 | 2.2603e-003 |
| 4.0949e+000 | 5.8263e-002 | 1.3516e-003 |
| 4.9417e+000 | 3.8098e-002 | 8.3082e-004 |
| 5.9636e+000 | 2.4820e-002 | 5.1991e-004 |
| 7.1969e+000 | 1.6018e-002 | 3.2778e-004 |
| 8.6851e+000 | 1.0307e-002 | 2.0865e-004 |
| 1.0481e+001 | 6.5858e-003 | 1.3277e-004 |
| 1.2649e+001 | 4.0867e-003 | 8.2477e-005 |
| 1.5264e+001 | 2.4924e-003 | 5.0759e-005 |
| 1.8421e+001 | 1.5081e-003 | 3.0753e-005 |
| 2.2230e+001 | 7.8848e-004 | 1.6160e-005 |
| 2.6827e+001 | 1.7444e-004 | 3.6300e-006 |
| 3.2375e+001 | 2.2576e-006 | 7.8680e-008 |
| 3.9069e+001 | 1.1507e-006 | 4.2359e-008 |
| 4.7149e+001 | 6.1320e-007 | 2.3204e-008 |
| 5.6899e+001 | 3.0449e-007 | 1.1829e-008 |
| 6.8665e+001 | 1.2716e-007 | 5.0834e-009 |
| 8.2864e+001 | 2.8523e-008 | 1.1637e-009 |
| 1.0000e+002 | 0.0000e+000 | 0.0000e+000 |

File: FS93L422.DEV     Input device parameter file used for solar minimum validation run.


```
Tested on 22 May 1987 at LBL 88 cyclotron by R. Koga
First column is in MeV/mg/cm2
Second column is cross section in cm2/device
X=39 Y=39 Z=1 N=1024
LET(MeV/mg/cm2)  Cross-Section (cm2/device)  for Fairchild 93L422 RAM
      0.5               0.0
      1.0               2.83e-5
      1.2               5.54e-5
      1.4               2.83e-4
      2.0               6.62e-4
      3.0               5.40e-3
      4.2               6.63e-3
      5.5               7.06e-3
      8.2               1.02e-2
      9.6               1.34e-2
      15.               1.45e-2
      21.               1.55e-2
      30.               1.6e-2
      42.               1.6e-2
```


File: AM93L422.DEV     Input device parameter file used for solar minimum validation run.


```
 X=39   Y=39   Z=1   N=1024
 The example given here is the measured
 upset cross section for an AMD 93L422 RAM
 tested 22 May 1987 at LBL 88" cyclotron.
LET(MeV/mg/cm2)  Cross-Section (cm2/device)   for AMD 93L422 RAM
     0.1               0.0
     0.5               1.00e-4
     1.0               3.23e-3
     1.4               4.34e-3
     3.0               5.77e-3
     4.2               1.05e-2
     5.5               1.10e-2
     8.2               1.15e-2
     9.6               1.20e-2
    15.0               1.29e-2
    21.0               1.30e-2
    30.0               1.40e-2
    35.0               1.40e-2
    42.0               1.40e-2
```

**File: SOLARMIN.SEU   Upset rate output file used for solar minimum validation run.**

```
SEU rate calculator  -  1-D integration method
Integral over experimental cross-section data.
CRRES/SPACERAD Heavy Ion Model of the Environment V3.5
SEU calculation date: Mon Jan 20 14:55:39 1997

Convergence set to:   High (0.1% consistency, slower computation)
LET Spectrum Output File from CHIME V3.5

Model file name: SOLARMIN.CHM      Dated: Mon Jan 20 09:05:22 1997
Solar minimum conditions, phi = 400 MV, no solar particle fluxes
Typical space station/MIR orbit: 430 km altitude, 51 deg inclination

Galactic cosmic ray spectrum for level of solar modulation phi = 400 MV

No solar flare heavy ion enhancement included.

Geomagnetic shielding effects included.

Specification for orbit and geomagnetic shielding calculation:
    Perigee altitude in kilometers = 430
    Apogee altitude in kilometers = 430
    Perigee angle in degrees, Beta = 0.00
    Inclination angle in degrees = 51.00
    Longitude of ascending node in degrees = 0.00
    Day of year of orbit, Tomega = 265.00
    Time of perigee in seconds, Tzero = 0.0
    Start time in seconds = 0.0
    Integration time in seconds, Delta_t = 100.0
    End time in seconds = 86400.0
Orbital Period =5.581780e+003 seconds

Average Integral Linear Energy Transfer Spectrum
Shield thickness = 1.0000e+003 mg/cm^2 = 1.0000e+003 mg/cm2
Sensitive region = 1.0000e+001 microns Si = 2.3300e+000 mg/cm2
Elements used with atomic number Z = 1 to 92

 Linear E Xfer   Interplanetary GeoMag-shielded
LET(MeV/mg/cm2) Flux/(m2 s sr) Flux/(m2 s sr)
  1.0000e-002        2.2092e+002        1.2649e+001
  1.2068e-002        1.6404e+002        9.8221e+000
  1.4563e-002        1.2562e+002        8.3053e+000
  1.7575e-002        9.8910e+001        7.3724e+000
  2.1210e-002        8.1164e+001        6.9994e+000
  2.5595e-002        6.9111e+001        6.7624e+000
  3.0888e-002        6.0384e+001        6.5217e+000
  3.7276e-002        5.4292e+001        6.4106e+000
  4.4984e-002        4.8598e+001        5.9804e+000
  5.4287e-002        4.4006e+001        5.7448e+000
  6.5513e-002        3.6540e+001        4.4282e+000
  7.9060e-002        3.1393e+001        4.0161e+000
```

| | | |
|---|---|---|
| 9.5410e-002 | 2.6725e+001 | 3.5547e+000 |
| 1.1514e-001 | 2.0007e+001 | 2.1887e+000 |
| 1.3895e-001 | 1.5746e+001 | 1.8366e+000 |
| 1.6768e-001 | 1.2752e+001 | 1.5473e+000 |
| 2.0236e-001 | 1.0383e+001 | 1.3517e+000 |
| 2.4421e-001 | 8.3507e+000 | 1.0557e+000 |
| 2.9471e-001 | 6.6484e+000 | 8.7120e-001 |
| 3.5565e-001 | 5.0303e+000 | 6.1101e-001 |
| 4.2919e-001 | 3.9893e+000 | 5.1003e-001 |
| 5.1795e-001 | 3.2499e+000 | 4.4814e-001 |
| 6.2506e-001 | 2.7066e+000 | 3.9595e-001 |
| 7.5431e-001 | 2.2557e+000 | 3.4487e-001 |
| 9.1030e-001 | 1.8865e+000 | 2.9744e-001 |
| 1.0985e+000 | 1.4272e+000 | 1.7608e-001 |
| 1.3257e+000 | 7.8438e-001 | 4.9727e-002 |
| 1.5999e+000 | 4.9473e-001 | 2.3693e-002 |
| 1.9307e+000 | 3.1967e-001 | 1.2477e-002 |
| 2.3300e+000 | 2.0828e-001 | 6.8865e-003 |
| 2.8118e+000 | 1.3612e-001 | 3.9065e-003 |
| 3.3932e+000 | 8.8986e-002 | 2.2603e-003 |
| 4.0949e+000 | 5.8263e-002 | 1.3516e-003 |
| 4.9417e+000 | 3.8098e-002 | 8.3082e-004 |
| 5.9636e+000 | 2.4820e-002 | 5.1991e-004 |
| 7.1969e+000 | 1.6018e-002 | 3.2778e-004 |
| 8.6851e+000 | 1.0307e-002 | 2.0865e-004 |
| 1.0481e+001 | 6.5858e-003 | 1.3277e-004 |
| 1.2649e+001 | 4.0867e-003 | 8.2477e-005 |
| 1.5264e+001 | 2.4924e-003 | 5.0759e-005 |
| 1.8421e+001 | 1.5081e-003 | 3.0753e-005 |
| 2.2230e+001 | 7.8848e-004 | 1.6160e-005 |
| 2.6827e+001 | 1.7444e-004 | 3.6300e-006 |
| 3.2375e+001 | 2.2576e-006 | 7.8680e-008 |
| 3.9069e+001 | 1.1507e-006 | 4.2359e-008 |
| 4.7149e+001 | 6.1320e-007 | 2.3204e-008 |
| 5.6899e+001 | 3.0449e-007 | 1.1829e-008 |
| 6.8665e+001 | 1.2716e-007 | 5.0834e-009 |
| 8.2864e+001 | 2.8523e-008 | 1.1637e-009 |
| 1.0000e+002 | 0.0000e+000 | 0.0000e+000 |

Device Upset Cross-Section Tabulation:
LET(MeV/mg/cm2)   Cross-Section (cm2/device)   for Fairchild 93L422 RAM

| LET(MeV/mg/cm2) | Cross-section(cm2/device) |
|---|---|
| 5.0000e-001 | 0.0000e+000 |
| 1.0000e+000 | 2.8300e-005 |
| 1.2000e+000 | 5.5400e-005 |
| 1.4000e+000 | 2.8300e-004 |
| 2.0000e+000 | 6.6200e-004 |
| 3.0000e+000 | 5.4000e-003 |
| 4.2000e+000 | 6.6300e-003 |
| 5.5000e+000 | 7.0600e-003 |
| 8.2000e+000 | 1.0200e-002 |
| 9.6000e+000 | 1.3400e-002 |
| 1.5000e+001 | 1.4500e-002 |

```
        2.1000e+001        1.5500e-002
        3.0000e+001        1.6000e-002
        4.2000e-001        1.6000e-002
Sensitive region (microns):  X = 39.00  Y = 39.00  Z = 1.00
Number of bits per device = 1024
Density of material in device is 2330 mg/cm2 for silicon
Cross section set.  13 values tabulated


Interplanetary (worst-case) LET spectrum set.  49 values tabulated


Integrating each part of cross-section curve for SEU rate.
Part  1 of 13   Qc=1.1650e-001   Xs=0.0000e+000   I=0.0000e+000
Part  2 of 13   Qc=2.3300e-001   Xs=1.8170e-003   I=5.5365e-006
Part  3 of 13   Qc=2.7960e-001   Xs=3.5570e-003   I=8.7666e-006
Part  4 of 13   Qc=3.2620e-001   Xs=1.8170e-002   I=3.6315e-005
Part  5 of 13   Qc=4.6600e-001   Xs=4.2504e-002   I=4.9358e-005
Part  6 of 13   Qc=6.9900e-001   Xs=3.4671e-001   I=2.0603e-004
Part  7 of 13   Qc=9.7860e-001   Xs=4.2568e-001   I=1.4094e-004
Part  8 of 13   Qc=1.2815e+000   Xs=4.5329e-001   I=9.2430e-005
Part  9 of 13   Qc=1.9106e+000   Xs=6.5489e-001   I=6.3982e-005
Part 10 of 13   Qc=2.2368e+000   Xs=8.6035e-001   I=6.2432e-005
Part 11 of 13   Qc=3.4950e+000   Xs=9.3098e-001   I=2.8406e-005
Part 12 of 13   Qc=4.8930e+000   Xs=9.9518e-001   I=1.5458e-005
Part 13 of 13   Qc=6.9900e+000   Xs=1.0273e+000   I=7.5066e-006


Interplanetary (worst-case) Integration Complete.
Interplanetary (worst-case) result = 5.629e-004 upsets per bit per day
Limiting range is 3.178e-004 to 5.736e-004 upsets per bit per day
Interplanetary (worst-case) result = 5.764e-001 upsets per device per day
Limiting range is 3.255e-001 to 5.873e-001 upsets per device per day


Geo-Magnetically Shielded LET spectrum set.  49 values tabulated


Integrating each part of cross-section curve for SEU rate.
Part  1 of 13   Qc=1.1650e-001   Xs=0.0000e+000   I=0.0000e+000
Part  2 of 13   Qc=2.3300e-001   Xs=1.8170e-003   I=7.5322e-007
Part  3 of 13   Qc=2.7960e-001   Xs=3.5570e-003   I=1.1788e-006
Part  4 of 13   Qc=3.2620e-001   Xs=1.8170e-002   I=4.6923e-006
Part  5 of 13   Qc=4.6600e-001   Xs=4.2504e-002   I=5.7265e-006
Part  6 of 13   Qc=6.9900e-001   Xs=3.4671e-001   I=2.1407e-005
Part  7 of 13   Qc=9.7860e-001   Xs=4.2568e-001   I=1.3498e-005
Part  8 of 13   Qc=1.2815e+000   Xs=4.5329e-001   I=8.3289e-006
Part  9 of 13   Qc=1.9106e+000   Xs=6.5489e-001   I=5.3505e-006
Part 10 of 13   Qc=2.2368e+000   Xs=8.6035e-001   I=5.0636e-006
Part 11 of 13   Qc=3.4950e+000   Xs=9.3098e-001   I=2.1093e-006
Part 12 of 13   Qc=4.8930e+000   Xs=9.9518e-001   I=1.0850e-006
Part 13 of 13   Qc=6.9900e+000   Xs=1.0273e+000   I=4.9281e-007


Geo-Magnetically Shielded Integration Complete.
Geo-Magnetically Shielded result = 6.393e-005 upsets per bit per day
Limiting range is 3.328e-005 to 6.532e-005 upsets per bit per day
Geo-Magnetically Shielded result = 6.547e-002 upsets per device per day
Limiting range is 3.408e-002 to 6.688e-002 upsets per device per day
***************************** End of Run *****************************
```

```
*************************************************************************

SEU rate calculator  -  1-D integration method
Integral over experimental cross-section data.
CRRES/SPACERAD Heavy Ion Model of the Environment V3.5
SEU calculation date: Mon Jan 20 15:04:16 1997

Convergence set to:   High (0.1% consistency, slower computation)
LET Spectrum Output File from CHIME V3.5

Model file name: SOLARMIN.CHM      Dated: Mon Jan 20 09:05:22 1997
Solar minimum conditions, phi = 400 MV, no solar particle fluxes
Typical space station/MIR orbit: 430 km altitude, 51 deg inclination

Galactic cosmic ray spectrum for level of solar modulation phi = 400 MV

No solar flare heavy ion enhancement included.

Geomagnetic shielding effects included.

Specification for orbit and geomagnetic shielding calculation:
    Perigee altitude in kilometers = 430
    Apogee altitude in kilometers = 430
    Perigee angle in degrees, Beta = 0.00
    Inclination angle in degrees = 51.00
    Longitude of ascending node in degrees = 0.00
    Day of year of orbit, Tomega = 265.00
    Time of perigee in seconds, Tzero = 0.0
    Start time in seconds = 0.0
    Integration time in seconds, Delta_t = 100.0
    End time in seconds = 86400.0
Orbital Period =5.581780e+003 seconds

Average Integral Linear Energy Transfer Spectrum
Shield thickness = 1.0000e+003 mg/cm^2 = 1.0000e+003 mg/cm2
Sensitive region = 1.0000e+001 microns Si = 2.3300e+000 mg/cm2
Elements used with atomic number Z = 1 to 92
```

| Linear E Xfer LET(MeV/mg/cm2) | Interplanetary Flux/(m2 s sr) | GeoMag-shielded Flux/(m2 s sr) |
|---|---|---|
| 1.0000e-002 | 2.2092e+002 | 1.2649e+001 |
| 1.2068e-002 | 1.6404e+002 | 9.8221e+000 |
| 1.4563e-002 | 1.2562e+002 | 8.3053e+000 |
| 1.7575e-002 | 9.8910e+001 | 7.3724e+000 |
| 2.1210e-002 | 8.1164e+001 | 6.9994e+000 |
| 2.5595e-002 | 6.9111e+001 | 6.7624e+000 |
| 3.0888e-002 | 6.0384e+001 | 6.5217e+000 |
| 3.7276e-002 | 5.4292e+001 | 6.4106e+000 |
| 4.4984e-002 | 4.8598e+001 | 5.9804e+000 |
| 5.4287e-002 | 4.4006e+001 | 5.7448e+000 |
| 6.5513e-002 | 3.6540e+001 | 4.4282e+000 |
| 7.9060e-002 | 3.1393e+001 | 4.0161e+000 |
| 9.5410e-002 | 2.6725e+001 | 3.5547e+000 |

| | | |
|---|---|---|
| 1.1514e-001 | 2.0007e+001 | 2.1887e+000 |
| 1.3895e-001 | 1.5746e+001 | 1.8366e+000 |
| 1.6768e-001 | 1.2752e+001 | 1.5473e+000 |
| 2.0236e-001 | 1.0383e+001 | 1.3517e+000 |
| 2.4421e-001 | 8.3507e+000 | 1.0557e+000 |
| 2.9471e-001 | 6.6484e+000 | 8.7120e-001 |
| 3.5565e-001 | 5.0303e+000 | 6.1101e-001 |
| 4.2919e-001 | 3.9893e+000 | 5.1003e-001 |
| 5.1795e-001 | 3.2499e+000 | 4.4814e-001 |
| 6.2506e-001 | 2.7066e+000 | 3.9595e-001 |
| 7.5431e-001 | 2.2557e+000 | 3.4487e-001 |
| 9.1030e-001 | 1.8865e+000 | 2.9744e-001 |
| 1.0985e+000 | 1.4272e+000 | 1.7608e-001 |
| 1.3257e+000 | 7.8438e-001 | 4.9727e-002 |
| 1.5999e+000 | 4.9473e-001 | 2.3693e-002 |
| 1.9307e+000 | 3.1967e-001 | 1.2477e-002 |
| 2.3300e+000 | 2.0828e-001 | 6.8865e-003 |
| 2.8118e+000 | 1.3612e-001 | 3.9065e-003 |
| 3.3932e+000 | 8.8986e-002 | 2.2603e-003 |
| 4.0949e+000 | 5.8263e-002 | 1.3516e-003 |
| 4.9417e+000 | 3.8098e-002 | 8.3082e-004 |
| 5.9636e+000 | 2.4820e-002 | 5.1991e-004 |
| 7.1969e+000 | 1.6018e-002 | 3.2778e-004 |
| 8.6851e+000 | 1.0307e-002 | 2.0865e-004 |
| 1.0481e+001 | 6.5858e-003 | 1.3277e-004 |
| 1.2649e+001 | 4.0867e-003 | 8.2477e-005 |
| 1.5264e+001 | 2.4924e-003 | 5.0759e-005 |
| 1.8421e+001 | 1.5081e-003 | 3.0753e-005 |
| 2.2230e+001 | 7.8848e-004 | 1.6160e-005 |
| 2.6827e+001 | 1.7444e-004 | 3.6300e-006 |
| 3.2375e+001 | 2.2576e-006 | 7.8680e-008 |
| 3.9069e+001 | 1.1507e-006 | 4.2359e-008 |
| 4.7149e+001 | 6.1320e-007 | 2.3204e-008 |
| 5.6899e+001 | 3.0449e-007 | 1.1829e-008 |
| 6.8665e+001 | 1.2716e-007 | 5.0834e-009 |
| 8.2864e+001 | 2.8523e-008 | 1.1637e-009 |
| 1.0000e+002 | 0.0000e+000 | 0.0000e+000 |

Device Upset Cross-Section Tabulation:
LET(MeV/mg/cm2)   Cross-Section (cm2/device)   for AMD 93L422 RAM

| LET(MeV/mg/cm2) | Cross-section(cm2/device) |
|---|---|
| 1.0000e-001 | 0.0000e+000 |
| 5.0000e-001 | 1.0000e-004 |
| 1.0000e+000 | 3.2300e-003 |
| 1.4000e+000 | 4.3400e-003 |
| 3.0000e+000 | 5.7700e-003 |
| 4.2000e+000 | 1.0500e-002 |
| 5.5000e+000 | 1.1000e-002 |
| 8.2000e+000 | 1.1500e-002 |
| 9.6000e+000 | 1.2000e-002 |
| 1.5000e+001 | 1.2900e-002 |
| 2.1000e+001 | 1.3000e-002 |
| 3.0000e+001 | 1.4000e-002 |

```
       3.5000e+001        1.4000e-002
       4.2000e+001        1.4000e-002
Sensitive region (microns):   X = 39.00   Y = 39.00   Z = 1.00
Number of bits per device = 1024
Density of material in device is 2330 mg/cm2 for silicon
Cross section set.   12 values tabulated


Interplanetary (worst-case) LET spectrum set.   49 values tabulated


Integrating each part of cross-section curve for SEU rate.
Part  1 of 12    Qc=2.3300e-002   Xs=0.0000e+000   I=0.0000e+000
Part  2 of 12    Qc=1.1650e-001   Xs=6.4205e-003   I=4.2454e-005
Part  3 of 12    Qc=2.3300e-001   Xs=2.0738e-001   I=6.3191e-004
Part  4 of 12    Qc=3.2620e-001   Xs=2.7865e-001   I=5.5691e-004
Part  5 of 12    Qc=6.9900e-001   Xs=3.7046e-001   I=2.2014e-004
Part  6 of 12    Qc=9.7860e-001   Xs=6.7416e-001   I=2.2321e-004
Part  7 of 12    Qc=1.2815e+000   Xs=7.0626e-001   I=1.4401e-004
Part  8 of 12    Qc=1.9106e+000   Xs=7.3836e-001   I=7.2136e-005
Part  9 of 12    Qc=2.2368e+000   Xs=7.7046e-001   I=5.5909e-005
Part 10 of 12    Qc=3.4950e+000   Xs=8.2825e-001   I=2.5272e-005
Part 11 of 12    Qc=4.8930e+000   Xs=8.3467e-001   I=1.2965e-005
Part 12 of 12    Qc=6.9900e+000   Xs=8.9887e-001   I=6.5683e-006


Interplanetary (worst-case) Integration Complete.
Interplanetary (worst-case) result = 1.913e-003 upsets per bit per day
Limiting range is 9.667e-004 to 1.978e-003 upsets per bit per day
Interplanetary (worst-case) result = 1.959e+000 upsets per device per day
Limiting range is 9.899e-001 to 2.026e+000 upsets per device per day


Geo-Magnetically Shielded LET spectrum set.   49 values tabulated


Integrating each part of cross-section curve for SEU rate.
Part  1 of 12    Qc=2.3300e-002   Xs=0.0000e+000   I=0.0000e+000
Part  2 of 12    Qc=1.1650e-001   Xs=6.4205e-003   I=5.2534e-006
Part  3 of 12    Qc=2.3300e-001   Xs=2.0738e-001   I=8.5968e-005
Part  4 of 12    Qc=3.2620e-001   Xs=2.7865e-001   I=7.1960e-005
Part  5 of 12    Qc=6.9900e-001   Xs=3.7046e-001   I=2.2873e-005
Part  6 of 12    Qc=9.7860e-001   Xs=6.7416e-001   I=2.1376e-005
Part  7 of 12    Qc=1.2815e+000   Xs=7.0626e-001   I=1.2977e-005
Part  8 of 12    Qc=1.9106e+000   Xs=7.3836e-001   I=6.0324e-006
Part  9 of 12    Qc=2.2368e+000   Xs=7.7046e-001   I=4.5346e-006
Part 10 of 12    Qc=3.4950e+000   Xs=8.2825e-001   I=1.8766e-006
Part 11 of 12    Qc=4.8930e+000   Xs=8.3467e-001   I=9.1004e-007
Part 12 of 12    Qc=6.9900e+000   Xs=8.9887e-001   I=4.3120e-007


Geo-Magnetically Shielded Integration Complete.
Geo-Magnetically Shielded result = 2.363e-004 upsets per bit per day
Limiting range is 1.235e-004 to 2.440e-004 upsets per bit per day
Geo-Magnetically Shielded result = 2.420e-001 upsets per device per day
Limiting range is 1.264e-001 to 2.498e-001 upsets per device per day
***************************** End of Run *****************************
```

66

```
****************************************************************************
```

SEU rate calculator  -  1-D integration method
Integral over experimental cross-section data.
CRRES/SPACERAD Heavy Ion Model of the Environment V3.5
SEU calculation date: Mon Jan 20 15:19:52 1997

Convergence set to:   High (0.1% consistency, slower computation)
LET Spectrum Output File from CHIME V3.5

Model file name: SOLARMIN.CHM      Dated: Mon Jan 20 09:05:22 1997
Solar minimum conditions, phi = 400 MV, no solar particle fluxes
Typical space station/MIR orbit: 430 km altitude, 51 deg inclination

Galactic cosmic ray spectrum for level of solar modulation phi = 400 MV

No solar flare heavy ion enhancement included.

Geomagnetic shielding effects included.

Specification for orbit and geomagnetic shielding calculation:
    Perigee altitude in kilometers = 430
    Apogee altitude in kilometers = 430
    Perigee angle in degrees, Beta = 0.00
    Inclination angle in degrees = 51.00
    Longitude of ascending node in degrees = 0.00
    Day of year of orbit, Tomega = 265.00
    Time of perigee in seconds, Tzero = 0.0
    Start time in seconds = 0.0
    Integration time in seconds, Delta_t = 100.0
    End time in seconds = 86400.0
Orbital Period =5.581780e+003 seconds

Average Integral Linear Energy Transfer Spectrum
Shield thickness = 1.0000e+003 mg/cm^2 = 1.0000e+003 mg/cm2
Sensitive region = 1.0000e+001 microns Si = 2.3300e+000 mg/cm2
Elements used with atomic number Z = 1 to 92

67

| Linear E Xfer LET(MeV/mg/cm2) | Interplanetary Flux/(m2 s r) | GeoMag-shielded Flux/(m2 s sr) |
|---|---|---|
| 1.0000e-002 | 2.2092e+002 | 1.2649e+001 |
| 1.2068e-002 | 1.6404e+002 | 9.8221e+000 |
| 1.4563e-002 | 1.2562e+002 | 8.3053e+000 |
| 1.7575e-002 | 9.8910e+001 | 7.3724e+000 |
| 2.1210e-002 | 8.1164e+001 | 6.9994e+000 |
| 2.5595e-002 | 6.9111e+001 | 6.7624e+000 |
| 3.0888e-002 | 6.0384e+001 | 6.5217e+000 |
| 3.7276e-002 | 5.4292e+001 | 6.4106e+000 |
| 4.4984e-002 | 4.8598e+001 | 5.9804e+000 |
| 5.4287e-002 | 4.4006e+001 | 5.7448e+000 |
| 6.5513e-002 | 3.6540e+001 | 4.4282e+000 |
| 7.9060e-002 | 3.1393e+001 | 4.0161e+000 |
| 9.5410e-002 | 2.6725e+001 | 3.5547e+000 |
| 1.1514e-001 | 2.0007e+001 | 2.1887e+000 |
| 1.3895e-001 | 1.5746e+001 | 1.8366e+000 |
| 1.6768e-001 | 1.2752e+001 | 1.5473e+000 |
| 2.0236e-001 | 1.0383e+001 | 1.3517e+000 |
| 2.4421e-001 | 8.3507e+000 | 1.0557e+000 |
| 2.9471e-001 | 6.6484e+000 | 8.7120e-001 |
| 3.5565e-001 | 5.0303e+000 | 6.1101e-001 |
| 4.2919e-001 | 3.9893e+000 | 5.1003e-001 |
| 5.1795e-001 | 3.2499e+000 | 4.4814e-001 |
| 6.2506e-001 | 2.7066e+000 | 3.9595e-001 |
| 7.5431e-001 | 2.2557e+000 | 3.4487e-001 |
| 9.1030e-001 | 1.8865e+000 | 2.9744e-001 |
| 1.0985e+000 | 1.4272e+000 | 1.7608e-001 |
| 1.3257e+000 | 7.8438e-001 | 4.9727e-002 |
| 1.5999e+000 | 4.9473e-001 | 2.3693e-002 |
| 1.9307e+000 | 3.1967e-001 | 1.2477e-002 |
| 2.3300e+000 | 2.0828e-001 | 6.8865e-003 |
| 2.8118e+000 | 1.3612e-001 | 3.9065e-003 |
| 3.3932e+000 | 8.8986e-002 | 2.2603e-003 |
| 4.0949e+000 | 5.8263e-002 | 1.3516e-003 |
| 4.9417e+000 | 3.8098e-002 | 8.3082e-004 |
| 5.9636e+000 | 2.4820e-002 | 5.1991e-004 |
| 7.1969e+000 | 1.6018e-002 | 3.2778e-004 |
| 8.6851e+000 | 1.0307e-002 | 2.0865e-004 |
| 1.0481e+001 | 6.5858e-003 | 1.3277e-004 |
| 1.2649e+001 | 4.0867e-003 | 8.2477e-005 |
| 1.5264e+001 | 2.4924e-003 | 5.0759e-005 |
| 1.8421e+001 | 1.5081e-003 | 3.0753e-005 |
| 2.2230e+001 | 7.8848e-004 | 1.6160e-005 |
| 2.6827e+001 | 1.7444e-004 | 3.6300e-006 |
| 3.2375e+001 | 2.2576e-006 | 7.8680e-008 |
| 3.9069e+001 | 1.1507e-006 | 4.2359e-008 |
| 4.7149e+001 | 6.1320e-007 | 2.3204e-008 |
| 5.6899e+001 | 3.0449e-007 | 1.1829e-008 |
| 6.8665e+001 | 1.2716e-007 | 5.0834e-009 |
| 8.2864e+001 | 2.8523e-008 | 1.1637e-009 |
| 1.0000e+002 | 0.0000e+000 | 0.0000e+000 |

```
Device Upset Cross-Section Tabulation:

LET(MeV/mg/cm2)   Cross-section(cm2/device)
     7.0000e-001       1.4000e-002
Sensitive region (microns):  X = 39.00  Y = 39.00  Z = 1.00
Number of bits per device = 1024
Density of material in device is 2330 mg/cm2 for silicon
Cross section set.  1 values tabulated

Interplanetary (worst-case) LET spectrum set.  49 values tabulated

Integrating each part of cross-section curve for SEU rate.
Part  1 of  1   Qc=1.6310e-001  Xs=8.9887e-001  I=4.0521e-003

Interplanetary (worst-case) Integration Complete.
Interplanetary (worst-case) result = 4.052e-003 upsets per bit per day
Interplanetary (worst-case) result = 4.149e+000 upsets per device per day

Geo-Magnetically Shielded LET spectrum set.  49 values tabulated

Integrating each part of cross-section curve for SEU rate.
Part  1 of  1   Qc=1.6310e-001  Xs=8.9887e-001  I=5.2365e-004

Geo-Magnetically Shielded Integration Complete.
Geo-Magnetically Shielded result = 5.236e-004 upsets per bit per day
Geo-Magnetically Shielded result = 5.362e-001 upsets per device per day
***************************** End of Run *****************************
```

```
**************************************************************************

SEU rate calculator  -  1-D integration method
Integral over experimental cross-section data.
CRRES/SPACERAD Heavy Ion Model of the Environment V3.5
SEU calculation date: Mon Jan 20 15:20:58 1997

Convergence set to:   High (0.1% consistency, slower computation)
LET Spectrum Output File from CHIME V3.5

Model file name: SOLARMIN.CHM      Dated: Mon Jan 20 09:05:22 1997
Solar minimum conditions, phi = 400 MV, no solar particle fluxes
Typical space station/MIR orbit: 430 km altitude, 51 deg inclination

Galactic cosmic ray spectrum for level of solar modulation phi = 400 MV

No solar flare heavy ion enhancement included.

Geomagnetic shielding effects included.


Specification for orbit and geomagnetic shielding calculation:
    Perigee altitude in kilometers = 430
    Apogee altitude in kilometers = 430
    Perigee angle in degrees, Beta = 0.00
    Inclination angle in degrees = 51.00
    Longitude of ascending node in degrees = 0.00
    Day of year of orbit, Tomega = 265.00
    Time of perigee in seconds, Tzero = 0.0
    Start time in seconds = 0.0
    Integration time in seconds, Delta_t = 100.0
    End time in seconds = 86400.0
Orbital Period =5.581780e+003 seconds


Average Integral Linear Energy Transfer Spectrum
Shield thickness = 1.0000e+003 mg/cm^2 = 1.0000e+003 mg/cm2
Sensitive region = 1.0000e+001 microns Si = 2.3300e+000 mg/cm2
Elements used with atomic number Z = 1 to 92
```

| Linear E Xfer LET(MeV/mg/cm2) | Interplanetary Flux/(m2 s sr) | GeoMag-shielded Flux/(m2 s sr) |
|---|---|---|
| 1.0000e-002 | 2.2092e+002 | 1.2649e+001 |
| 1.2068e-002 | 1.6404e+002 | 9.8221e+000 |
| 1.4563e-002 | 1.2562e+002 | 8.3053e+000 |
| 1.7575e-002 | 9.8910e+001 | 7.3724e+000 |
| 2.1210e-002 | 8.1164e+001 | 6.9994e+000 |
| 2.5595e-002 | 6.9111e+001 | 6.7624e+000 |
| 3.0888e-002 | 6.0384e+001 | 6.5217e+000 |
| 3.7276e-002 | 5.4292e+001 | 6.4106e+000 |
| 4.4984e-002 | 4.8598e+001 | 5.9804e+000 |
| 5.4287e-002 | 4.4006e+001 | 5.7448e+000 |
| 6.5513e-002 | 3.6540e+001 | 4.4282e+000 |
| 7.9060e-002 | 3.1393e+001 | 4.0161e+000 |
| 9.5410e-002 | 2.6725e+001 | 3.5547e+000 |
| 1.1514e-001 | 2.0007e+001 | 2.1887e+000 |
| 1.3895e-001 | 1.5746e+001 | 1.8366e+000 |
| 1.6768e-001 | 1.2752e+001 | 1.5473e+000 |
| 2.0236e-001 | 1.0383e+001 | 1.3517e+000 |
| 2.4421e-001 | 8.3507e+000 | 1.0557e+000 |
| 2.9471e-001 | 6.6484e+000 | 8.7120e-001 |
| 3.5565e-001 | 5.0303e+000 | 6.1101e-001 |
| 4.2919e-001 | 3.9893e+000 | 5.1003e-001 |
| 5.1795e-001 | 3.2499e+000 | 4.4814e-001 |
| 6.2506e-001 | 2.7066e+000 | 3.9595e-001 |
| 7.5431e-001 | 2.2557e+000 | 3.4487e-001 |
| 9.1030e-001 | 1.8865e+000 | 2.9744e-001 |
| 1.0985e+000 | 1.4272e+000 | 1.7608e-001 |
| 1.3257e+000 | 7.8438e-001 | 4.9727e-002 |
| 1.5999e+000 | 4.9473e-001 | 2.3693e-002 |
| 1.9307e+000 | 3.1967e-001 | 1.2477e-002 |
| 2.3300e+000 | 2.0828e-001 | 6.8865e-003 |
| 2.8118e+000 | 1.3612e-001 | 3.9065e-003 |
| 3.3932e+000 | 8.8986e-002 | 2.2603e-003 |
| 4.0949e+000 | 5.8263e-002 | 1.3516e-003 |
| 4.9417e+000 | 3.8098e-002 | 8.3082e-004 |
| 5.9636e+000 | 2.4820e-002 | 5.1991e-004 |
| 7.1969e+000 | 1.6018e-002 | 3.2778e-004 |
| 8.6851e+000 | 1.0307e-002 | 2.0865e-004 |
| 1.0481e+001 | 6.5858e-003 | 1.3277e-004 |
| 1.2649e+001 | 4.0867e-003 | 8.2477e-005 |
| 1.5264e+001 | 2.4924e-003 | 5.0759e-005 |
| 1.8421e+001 | 1.5081e-003 | 3.0753e-005 |
| 2.2230e+001 | 7.8848e-004 | 1.6160e-005 |
| 2.6827e+001 | 1.7444e-004 | 3.6300e-006 |
| 3.2375e+001 | 2.2576e-006 | 7.8680e-008 |
| 3.9069e+001 | 1.1507e-006 | 4.2359e-008 |
| 4.7149e+001 | 6.1320e-007 | 2.3204e-008 |
| 5.6899e+001 | 3.0449e-007 | 1.1829e-008 |
| 6.8665e+001 | 1.2716e-007 | 5.0834e-009 |
| 8.2864e+001 | 2.8523e-008 | 1.1637e-009 |
| 1.0000e+002 | 0.0000e+000 | 0.0000e+000 |

Device Upset Cross-Section Tabulation:

LET(MeV/mg/cm2)   Cross-section(cm2/device)
    2.0000e+000        1.6000e-002
Sensitive region (microns):  X = 39.00  Y = 39.00  Z = 1.00
Number of bits per device = 1024
Density of material in device is 2330 mg/cm2 for silicon
Cross section set.  1 values tabulated


Interplanetary (worst-case) LET spectrum set.  49 values tabulated

Integrating each part of cross-section curve for SEU rate.
Part  1 of  1   Qc=4.6600e-001  Xs=1.0273e+000  I=1.1929e-003

Interplanetary (worst-case) Integration Complete.
Interplanetary (worst-case) result = 1.193e-003 upsets per bit per day
Interplanetary (worst-case) result = 1.222e+000 upsets per device per day

Geo-Magnetically Shielded LET spectrum set.  49 values tabulated

Integrating each part of cross-section curve for SEU rate.
Part  1 of  1   Qc=4.6600e-001  Xs=1.0273e+000  I=1.3840e-004

Geo-Magnetically Shielded Integration Complete.
Geo-Magnetically Shielded result = 1.384e-004 upsets per bit per day
Geo-Magnetically Shielded result = 1.417e-001 upsets per device per day
**************************** End of Run ****************************
******************************************************************